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EVALUATION OF RAPID-SETTING CONCRETES FOR AIRFIELD SPALL REPAIR

by

Lillian D. Wakeley, Tony B. Husbands, Charles L. White

Structures Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

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Lillian D. Wakeley
Tony B. Husbands
Charles L. White

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13. ABSTRACT *(Maximum 200 words)*

Three commercially available, off-the-shelf, rapid-setting materials were evaluated for their potential as spall-repair concretes for Rapid Runway Repair (RRR). The three were a methyl methacrylate binder (Silikal R17AF), a magnesium phosphate mortar mix (Set-45), and a high-performance blended cement mortar mix (Pyrament 505). Each was extended 50 percent by mass with coarse aggregate for these tests.

Test methods were chosen, or developed as required, to evaluate the performance of these three rapid-setting concretes in cold and wet conditions, as well as at room temperature. None of the materials performed ideally under all conditions. Silikal R17AF gives very high strengths in cold, dry conditions. But it bonds poorly to wet surfaces and loses much of its strength when mixed with wet aggregate. Pyrament 505 gains strength more slowly, especially at temperatures below 20 °F, but it bonds consistently well under all conditions tested. The

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Set-45 product evaluated could not be tested at temperatures below 40°F, due to insufficient strength even for removing specimens from the molds.

Compressive strength may not be the most important factor to consider when choosing a spall repair material. Flexural strength, early thermal history, and bond to existing concrete may be more critical for a shallow patch such as a spall repair. Further analyses are recommended for the materials that is least expensive, relatively nontoxic, and appears to be most versatile among these three (Pyrament 505).

Preface

The work described in this report is part of a research effort accomplished in the Concrete Technology Division (CTD), Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES), and coordinated via the Pavement Systems Division, Geotechnical Laboratory, GL, WES, under contract to the Air Force Engineering and Services Center (AFESC), Tyndall Air Force Base, FL. MAJ Bill Brinkley, AFESC/YE, was technical monitor for this effort, funded under MIPR N88-83, 21 Sep 88, and N89-41, 17 Feb 89.

Product trade names are used throughout the report, as requested by the sponsor. This work neither endorses nor criticizes the products evaluated. Also at the request of the sponsor, all test results are reported in non-SI units.

The laboratory analyses were completed between February and August, 1989, in CTD, and were directed by Mr. Tony B. Husbands, with assistance from Mrs. Judy C. Tom and Ms. M. Joyce Chapman, and Messrs. Charles White, Joe G. Tom, Fred Causey, Billy D. Neeley, and L. Webster Mason. Dr. Lillian D. Wakeley, CTD, and Drs. W. Newell Brabston and Philip G. Malone, GL, contributed to the planning and accomplishment of this work.

Preparation of this report was under the general supervision of Mr. Bryant Mather, Chief, SL; Mr. James T. Ballard, Assistant Chief, SL; and Mr. Kenneth L. Saucier, Chief, CTD. Dr. Wakeley and Messrs. Husbands and White prepared this report.

COL Larry B. Fulton, EN, is Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

Contents

Conversion Factors, Non-SI To SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
gallons (US liquid)	3.785412	litres
inches	25.4	millimetres
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square inches	645.16	square millimetres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

EVALUATION OF RAPID-SETTING CONCRETES FOR AIRFIELD SPALL REPAIR

Introduction

1. In January, 1989, the Air Force Engineering and Services Center (AFESC/YE), Tyndall Air Force Base requested that the Waterways Experiment Station (WES) evaluate three commercially available products with potential for use in repairing spalls on runways damaged in wartime conditions. This evaluation was requested in support of the Rapid Runway Repair (RRR) Program. Requirements of the evaluation process are recommended by the Concrete Technology Division (CTD), of the Structures Laboratory (SL) at WES, with the cooperation of the Pavement Systems Division, Geotechnical Laboratory, WES. The evaluation program was performed in the CTD between February and August, 1989.

2. The three materials evaluated were available commercially in the US as off-the-shelf products. Trade names for these materials are used throughout the report. Several of the tests conducted, or conditions of the tests, were designed to indicate the performance of these materials in environmental conditions judged to be meaningful for repair of spalls in adverse weather conditions, such as cold temperatures and standing water. The performance of these materials was different under these nonstandard conditions than it is if the materials are subjected to strictly standard tests.

3. None of the data reported herein indicate that any of the materials performs differently, under standard test conditions, than has been reported by their manufacturers. We have tried to describe tests adequately to clarify differences between these tests and standard (ASTM) requirements, and explain why the tests were performed as they were. Data from these non-standard analyses cannot be compared to any data published previously from standard tests. Our work neither endorses not criticizes the materials we evaluated.

Previous presentations

4. Preliminary results of this study were presented to the Seventh Airbase Wartime Damage Repair Coordination Committee Meeting, at WES in May 1989. In October 1989, the RRR Procedures Working Group and Test Plan Working Group heard results of the entire study during annual meetings at Ramstein Air Base. This report describes the evaluation program. The figures presented as

slides at those meetings are included in Appendix A. Additional slides shown at the October meetings are in Appendix B.

Definitions and Performance Requirements

Definition of spall repair

5. The Rapid Runway Repair Program of the US Air Force (USAF) includes the activities that must be performed to return an airfield, damaged during an attack, to a condition such that it will support launching and recovery of combat aircraft. The time goal is to accomplish all required repair activities within a few hours or less.

6. Spall repair is one component of the RRR Program. Spalls are defined as surface and minor base-course damage, with each individual spall having a diameter between 2 in. and 12 ft,* and a depth of 1 in. to 5 ft (RRR Test and Evaluation Master Plan [TEMP], Oct 89 [Draft]). Further, spalls are damage with which there is no upheaval of the surrounding pavement. The RRR scenario for wartime spall repair includes the expectation that a runway will be damaged by tens to hundreds of spalls at one time. The repair activity therefore will require filling many shallow spalls with a material that will permit aircraft traffic within 2 hr or less, but does not require removal of large areas of pavement surrounding each spall (pavement upheaval surrounds craters).

Performance requirements of materials for spall repair

7. Characteristics of the ideal spall repair material are: it is placeable in any weather conditions with trained personnel and a minimum of specialized equipment; it have a shelf life of 5 years; it be useful in more ordinary construction and repair so that stocks can be rotated; it be no more toxic than ordinary construction materials such as portland cement, so that it can be used without extensive protective gear; and it produce no toxic or hazardous wastes.

8. Using such a material or materials system, it should be possible to return a minimum operating strip (MOS) to service within a few hours after

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

infliction of damage. Of course, cost comparable to or not outrageously greater than that of portland-cement concrete (PCC) is desirable. The WES research project on potential spall repair materials included observations of or tests for many of these characteristics, or development of tests if no standard method was available or appropriate.

9. Other technical characteristics of a spall repair system given in the RRR TEMP were not part of this research program. For example, training and materials handling would be greatly simplified if the material were physically compatible with PCC, asphalt concrete, and asphalt or porous friction-surface overlays on concrete. The RRR Program TEMP also lists as a required technical characteristic that a repaired spall be able to withstand at least 10,000 tactical aircraft passes before replacement.

Aspects of performance
addressed in this study

10. The FY 89 program at WES tested some aspects of compatibility between repair materials and PCC. However, all tests were of early-age properties, specifically 1 and 4 hr for most tests and 24 hr for bond strength. The program did not include any tests or simulations of long-term service, such as would be required to determine how well the material would withstand thousands of aircraft passes.

11. Principal properties measured in this study were compressive and flexural strength, and bond to existing concrete. Performance of the materials in adverse environmental conditions was addressed by measuring these properties both at room temperature and at cold temperatures, and with the concretes having been prepared with both dry and wet aggregate. Other evaluations were devised such that the conditions in which concrete beams were cast simulated casting into water-filled spalls, following which flexural strength was determined. Bond strength also was evaluated following casting in adversely wet conditions (the manufacturers of Silikal and Set-45 both recommend that their materials, when used for patching, be cast against a dry surface).

12. The Project Plan developed by WES for this work is included as Appendix C. It was followed with only minor modification, as demanded by unanticipated materials properties.

13. Values required of a spall-repair material for such properties as

compressive and flexural strength, bond strength, and shrinkage were not available from AFESC when this study was begun. As recently as 1978, the NATO criterion for compressive strength of a crater-repair material was only 1,000 psi at 4 hr (Collum, Denson, and Hoff, 1978).

14. In the past few years, with the availability of new binders, expectations of early strength of repair materials have increased dramatically. The RRR program would like to field a spall-repair system the principal material of which achieves 400 psi flexural or approximately 4,000 psi compressive within 1 hr after placement. This value is based on the loading of an F-4 aircraft on concrete pavement (Boyer and Kistler, 1982).

15. For a shallow repair such as that in a small spall, 400 psi flexural strength is adequate to permit aircraft traffic to resume on repaired pavement (Boyer and Kistler, 1982).

Current Practice

16. When this study started, many Air Bases stocked Silikal (reg. trademark) for spall repair during wartime conditions, and for use during RRR training. Silikal is a methyl methacrylate, which forms a solid mass within minutes after its two components are mixed. It was chosen for RRR use because it sets and gains strength rapidly over a wide range of temperatures. It is considered to be the baseline material in this study, to which other candidate spall-repair materials are compared.

17. Characteristics of Silikal known at the beginning of this study to be non-ideal from the standpoint of RRR included: it is flammable; protective clothing and respirators are required for safe handling; the solvents used to clean mixing equipment are themselves toxic; and its cost per unit volume is up to forty times that of PCC.

Reasons for This Study

18. This work was undertaken for two reasons. The first was to determine if other commercially available rapid-setting cementitious materials could meet a reasonable subset of the spall-repair criteria without the non-ideal characteristics of flammability, toxicity, and high cost. The

second purpose arose from the high visibility and high-impact marketing of Pyrament (reg. trademark) cements, and interest in Pyrament products at high decisionmaking levels of the Department of Defense and other agencies. The second purpose for this work, then, was to begin assessing the RRR potential of Pyrament cements.

Materials and Manufacturers' Instructions

19. The three off-the-shelf materials studied are:

Material	Manufacturer	Type of Material
Silikal R17AF	Silikal North America, Inc.	Polymer concrete binder (methyl methacrylate)
Set-45	Master Builders, Inc.	Magnesium phosphate cement
Pyrament 505	Pyrament/Lone Star Industries, Inc.	Blended cement mortar mix

Product descriptions, mixing instructions, placement procedures, and safety precautions provided by the manufacturer of each material are summarized in this section. Not all of these recommended practices were followed in the WES study. Procedures were simplified as deemed appropriate for a RRR study and are described in a later section of this report. Properties as reported by the manufacturers in their material data sheets are included in Appendix D.

Silikal R17AF

20. Description and packaging. Silikal R17AF is a binder for polymer concrete that develops high early strengths. Its intended uses are for the repair of concrete, and for overlays and patching of concrete in service environments that would pose a chemical threat to PCC. A commercially available kit of Silikal R17AF contains the following:

a. 2480 lb R17AF Powder Component (4 drums, each drum containing 20 bags, 30 lb each).

b. 304 lb R17AF Liquid Component (8 pails, 38 lb each, or approximately 5 gal per pail).

c. 36 lb R41S Primer (18 cans, 2 lb each)

d. 1.5 lb Silikal Powder Hardener

21. Mixing. Silikal R17AF mortar can be mixed in the bag in which the powder component is packed, or in a dump mixer. The manufacturer recommends

that no more than 1/2 gal of the liquid component be added to one bag of the powder component. The amount of liquid component can be reduced to obtain a different mortar consistency. R17AF mortar mix can be extended with a dried pea gravel or coarse sand (No. 8 (2.36 mm) or larger) for applications greater than 1/2 in. thick. The largest aggregate size should not exceed one-third the depth of the patch. The mixture can be extended with aggregate to 150 percent by weight, adding the aggregate after the liquid and powder components have been mixed to ensure proper wetting. The manufacturer recommends that the concrete surface be primed with R41S Primer before application of the polymer concrete. For RRR applications, this step probably is not practical.

22. Repair surface preparation. Using a chipping hammer, remove any loose concrete from the area to be repaired and undercut the sides to provide a good fill area for the material. When cutting edges, the saw cut should be at least 1/4 in. in depth. Use dry compressed air, vacuum, or brush the surface to remove loose concrete, dust, and other debris. Wooden forms should be lined with polyethylene, or plastic laminate forms should be used.

23. Placement and finishing. If bags are used for mixing, cut the corner of the bag to let the mixed material run out into the area being repaired. The material should be placed within 15 min after addition of the liquid component. The mortar, or the mortar extended with 50 percent or less aggregate, is self-leveling and consolidation may not be necessary. If greater amounts of aggregate are added and the liquid component reduced, the polymer concrete can be consolidated using two-by-fours. Finish the patch or repair using standard concrete finishing methods. The tools and mixer can be cleaned with acetone or methyl ethyl ketone.

24. Safety. When working with Silikal R17AF and R41S materials, observe all regulations regarding flammable liquids. Adequate ventilation is essential, especially when working in a closed area. Always wear tight-fitting work clothes, rubber boots, gloves, goggles, and respirator, and avoid contact with skin or eyes. Material Safety Data Sheets are included in the kits, and are in Appendix E of this report.

Pyrament 505

25. Description and packaging. Pyrament 505 is a packaged mortar which requires only the addition of mixing water to produce a high early strength

material for the repair of concrete, and for new construction when high early strengths are needed. Pyrament 505 is packaged in 50-lb bags.

26. Mixing. Mix using a mortar mixer or high-intensity mixer. A drum mixer can be used when the material is extended with an aggregate. The material can be extended 60 percent by weight with coarse aggregate. The recommended amount of mixing water for one bag is 4.25 to 4.75 lb (4- to 4-1/2 pt). When mixing the mortar, add one-half the number of bags to be mixed, then all the mixing water. Mix for 1-1/2 min, then add the remainder of the material and mix for 5 to 8 min. When extending the material with coarse aggregate, place the coarse aggregate and one-half of the mixing water into the mixer and mix for 1-1/2 min. Add the Pyrament 505 and the remainder of the mixing water and mix an additional 5 to 8 min. Absorption and surface moisture of the coarse aggregate should be taken into consideration when calculating the total mixing water. Use 5 lb of mixing water for each bag of Pyrament 505 when extending with a dry coarse aggregate.

27. Repair surface preparation. When repairing spalled or deteriorated areas of concrete, chip or saw cut the spalled area to a depth sufficient to remove all deteriorated concrete. Edges should be squared, with a minimum depth of 1/2 in. Feather-edging *is not recommended.* All oil, grease, dirt, and loose debris should be removed from the surface or area to be repaired. Dampen the area to be repaired with clean water just prior to the start of the mixing cycle.

28. Placement. Place mixed material into the dampened, prepared area. Place from one side to the other, and work the mortar or concrete into sides and bottom of the repair area to assist in satisfactory bond. Screed and level to the elevation of existing concrete. Finish by trowel or other appropriate finishing methods. Do not retemper the mixture by adding water. Normal, ambient-temperature concrete curing methods should be followed. Approved curing compounds should provide satisfactory results and are recommended.

29. Safety. The use of barrier cream or impervious gloves, boots, and clothing to protect skin from contact with Pyrament 505 is recommended. Avoid breathing dust and provide eye protection. A Material Safety Data Sheet is included in Appendix E of this report.

Set-45

30. Description and packaging. Set-45 is a packaged magnesium

phosphate cement which requires only the addition of mixing water to produce a fast setting repair material for concrete that will support traffic in 45 min under certain conditions. It is packaged in 50-lb bags. Set-45 is available in a hot-weather formula, which is recommended when the ambient temperature is above 85 °F. The cold-weather formula cement was evaluated in the WES study.

31. Mixing. A drum or mortar mixer can be used to mix the material. For patches greater than 2 in. in depth, the manufacturer recommends the addition of coarse aggregate by adding up to 30 lb of dried, sound, round aggregate, graded between 1/4 and 1/2 in. (6.3 and 12.5 mm). When using crushed stone, the amount of aggregate may need to be reduced to obtain the desired consistency. The recommended amount of mixing water is 1/2 gal water per 50-lb bag of Set-45.

32. The manufacturer's mixing instructions are:

a. Pour mixing water into mixer.

b. Add coarse aggregate, if being used for deep fills. If damp aggregate is used, reduce the water to compensate.

c. Add Set-45 and mix approximately 60 to 90 sec. The material should be placed within 10 min of mixing.

33. Repair surface preparation. When repairing spalled or deteriorated areas of concrete, a 1/2-in.-deep or more saw cut should be made into sound concrete outside the area to be repaired, to form boundaries for the patch. Featheredge patching is not recommended. Remove all unsound concrete within the saw cut using a chipping hammer. All loose debris should be removed and the area cleaned of dust with compressed air or water. If water is used, air blast the area to remove water before placing Set-45.

34. Placement. Immediately place the mixed Set-45 into the prepared area, working the material firmly into the bottom and sides of the patch area to assure good bond. Do not use a bonding grout. Do not place Set-45 in lifts. Level the Set-45 and screed to the level of existing concrete. When correctly mixed, Set-45 is self-leveling. No curing is necessary for the material.

35. Safety. The use of barrier creams or impervious gloves, boots, and clothing to protect the skin from contact with Set-45 is recommended. Avoid breathing dust and provide eye protection. A Material Safety Data Sheet is provided in Appendix E of this report.

Mixture Proportions and Specimen Preparation

36. Mixture proportions. WES elected to evaluate concretes made with these three materials used as binders, rather than evaluate the materials without being extended by coarse aggregate, because of the ever-present desire to reduce materials costs. Although the manufacturers of these three materials recommended different maximum amounts of coarse aggregate, we used a constant amount, chosen to be within the recommended range for all three. Thus, all materials were evaluated for their performance as concrete, with the coarse aggregate proportioned as 50 percent by mass of prepackaged dry component. No fine aggregate was added, although Set-45 and Pyrament 505 both contain a sand component.

37. Test specimens were prepared from concretes proportioned as follows:

Silikal R17AF	Pyrament 505	Set-45
1 bag (30 lb) powder component	1 bag (50 lb)	1 bag (50 lb)
15 lb coarse aggregate	25 lb coarse agg	25 lb coarse agg
4 pt liquid component	4-1/2 pt water	4 pt water

The manufacturer of Pyrament 505 recommends that 10 percent additional water be added to the mixture for cold-weather applications. The amount of water was increased to 5 pt for each bag of Pyrament 505 for mixing and testing at cold temperatures (described below). With additional water, less mixing time was required.

Minimum test temperature and time of test

38. Tests of compressive and flexural strength were planned for 1 and 4 hr after mixing. Two temperatures were selected for determining compressive strength, bond strength, and shrinkage. The warmer temperature was 73 °F. Strength tests were successfully completed for all materials at 1 and 4 hr at this temperature.

39. We had intended to use a constant colder temperature of 20 °F or less for all three types of concrete. However, initial testing showed that neither Set-45 nor Pyrament 505 achieved enough strength in 1 hr at 20 °F to be demolded for testing. We then conducted additional tests, to determine the minimum temperature at which each material could be tested at 1 hr after

mixing. These temperatures were disappointingly high. We then lowered our expectations, and established minimum temperatures for testing at 2 hr. Table 1 shows minimum tests temperatures, and the compressive strength values achieved at the times and temperatures listed, under dry conditions. Tests to establish these values were of 6-in. cubes. All data reported for cold temperatures in the following sections were derived from the test temperatures shown in the column of Table 1 corresponding to a time of 2 hr after mixing.

40. Preparation of test specimens. For the mixing and casting of specimens for cold-temperature tests, the material and mixing water were cooled to 50 °F before mixing by placing the appropriate mass for each batch into an environmental chamber at least 24 hr before mixing was started. The coarse aggregate, mixing pail, mixing arm, and molds were also conditioned at the test temperature by placing them into the environmental chamber 24 hr before mixing. The mixing times at both temperatures for the materials after addition of the liquid are given in Table 2. The mixed material was placed into the mold, consolidated, then placed immediately back into the environmental chamber for the appropriate time.

41. As stated previously, the materials were extended with a coarse aggregate for testing. An extension of 50 percent coarse aggregate by mass of dry material was used in preparing the test specimens. The amount of aggregate was kept constant to obtain comparable test data. The coarse aggregate selected was a river-run chert gravel, conforming to the grading requirement of ASTM C 33-86 (ASTM 1988), size No. 67.

42. The properties of materials were determined using dry coarse aggregate and saturated-surface-wet coarse aggregate. The saturated-surface wet aggregate was obtained by weighing the dry aggregate in a plastic bag. Holes were then punched into the bag and the bag placed under water for a minimum time of 24 hr. Before placing the wet aggregate into the mixer, the bag was removed from underwater and the excess water was drained until water no longer flowed out through the holes.

43. The compressive and flexural strengths were determined at 1 and 4 hr after mixing was started. Bond strength to hardened concrete and shrinkage were determined 24 hr after mixing was started. The start of mixing was defined as the time the water or monomer (methyl methacrylate) was added to the cement or powder component. The mixing of the materials was accomplished

using a pail mixer which attaches directly to a 5-gal pail. This type of mixer was selected because the batches of materials were low in mass, and because it is a simple system which could be employed in RRR in lieu of large mixers.

Test Methods

Compressive strength

44. The compressive strengths of the materials were determined according to ASTM C 39-86 (ASTM 1988a), except for early cold temperatures for which 6-in. cubes were tested. The cylinder size for the test was 4 by 8 in. The static modulus of elasticity was determined according to ASTM C 469-87 (ASTM 1988b) using an extensometer.

45. One test specimen was prepared from a mixture of the material waiting 15 min between mixes so that the loading of the specimens could be started exactly at the designated time. The cylinders were stripped from the molds after hardening, 30 min for the Set-45 and Silikal, and 45 min for Pyrament 505. The cylinders were capped with a sulfur compound within 10 min before testing to provide flat parallel ends.

46. We had intended to use cube instead of cylinder specimens for cold-temperature tests, expecting that cold cylinders could not be capped successfully with the hot capping compound.

47. Initially, 2-in. cubes were to be tested for cold temperature studies. Early tests indicated that the mass of material in a 2-in. cube was too small to provide a realistic evaluation at the low temperatures. Accordingly, 6-in. cubes were cast for the low-temperature studies, and were tested approximately according to ASTM C 109-80 (ASTM 1988c). The freshly mixed material was placed into the mold and a thermocouple wire connected to a recorder was placed into the center of the material to monitor the temperature of the material as it set. The hardened cubes were stripped from the molds 5 min before testing and placed in a styrofoam container, which was conditioned in a freezer. The cube was removed from the container 30 sec before the designated test time.

Flexural strength

48. Specimens for flexural strength tests were fabricated and tested in accordance with ASTM C 78-84 (ASTM 1988d). The dimensions of the test specimens were 3-1/2 by 4-1/2 by 16 in. Twenty-minute intervals between mixes assured that the loading of the specimens could be started at the designated time.

49. The performance of the materials in a wet environment was determined by measuring the flexural strength of beams cast in a mold one-half full of water. The molds were first sealed with a heavy bead of silicone caulk to prevent any water leakage. The volume of water necessary to fill the mold one-half full was measured and poured into the mold (Figure 1). The mixed material was then placed into the mold as quickly as possible (Figure 2), the molds overfilled, and the material struck off using a small wooden board. No tamping, vibrating, or other compaction technique was used for consolidation. This procedure is not standard. It was developed to simulate the conditions of repairing a spall in the rain, when it is unlikely that any consolidation methods will be used.

Bond strength

50. The bond strength of the materials to hardened concrete was determined according to ASTM C 882-87 (ASTM 1988e) with certain modifications. The specimen molds were 4 by 8-in. cylinders instead of the 3 by 6-in. cylinders specified in the test method. The dummy sections, used to provide the correct shape and slant to half cylinders against which the repair material is cast, were prepared from a 4-in.-diam polyethylene cylinder. A dummy section along with a concrete half cylinder is shown in Figure 3. The half-cylinders were made from portland-cement concrete (PCC) having a 28-day compressive strength of 5,900 psi. The coarse aggregate used in preparing the PCC was a small chert aggregate (3/8-in. (9.5-mm) nominal maximum size). The diagonally cast bonding area of each half-cylinder was sandblasted lightly before preparing the test specimens. The specimens were prepared as described in section 10.3.3 of the test method except for the preparation of the bonding area of the half-cylinder. The manufacturers' recommended surface preparation was used. The bond strength was calculated by dividing the load carried by the specimen at failure by the area of the bonding surface (25.13 in.^{2}).

Figure 1. Filling of mold with water before material placement

Figure 2. Placement of material in mold

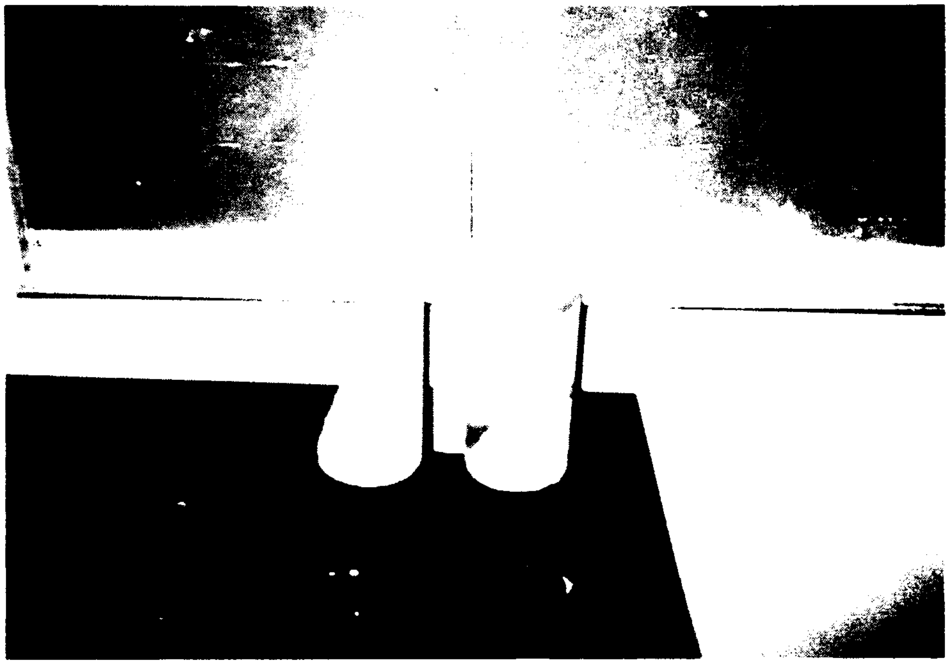

Figure 3. Dummy half cylinder and concrete half cylinder

51. To simulate bonding under wet conditions, the bond strength of the material to wet, hardened concrete was determined by soaking the half-cylinder in water 24 hr before preparing the test specimen. The face of the concrete half-cylinder to be bonded was blotted with a paper towel to remove the excess water from the surface before placing the half-cylinder into the mold. The material mixed with the saturated surface-wet aggregate was immediately placed into the mold.

Thermal contraction

52. The thermal contraction was determined using a DuPont shrinkage gauge as described in a Bureau of Reclamation report (Causey, 1983). The mold measuring 5 by 24 by 2-1/2 in. was constructed from 1/2-in.-thick plexiglass and coated with a Teflon film. The DuPont shrinkage gauge is shown in Figure 4. The thermal contraction was determined at 73 °F using both dry and wet aggregate. The thermal contraction was also determined at the low temperatures specified for each material. As was appropriate for cold-temperature mixing and testing, the DuPont gauge, mold, aggregate, mixing bowl, and paddle were placed in the environmental chamber at the test temperature 24 hr before mixing was started.

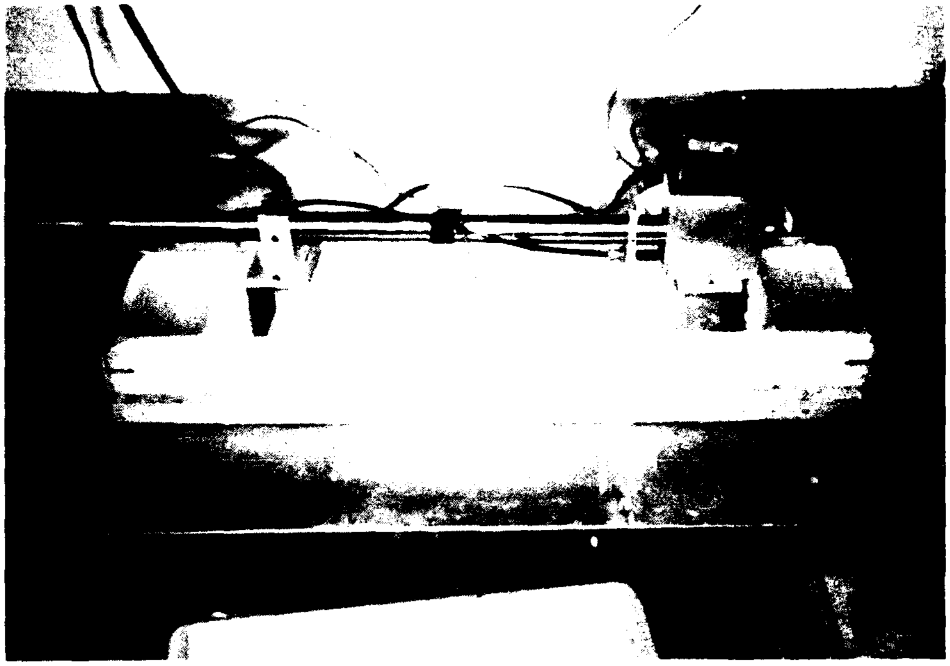

Figure 4. Dupont shrinkage gauge

Other tests

53. The initial and final setting time of Pyrament 505 and Set-45 were determined according to ASTM C 191-82 (ASTM 1988f). The amount of water recommended by the manufacturer was added to the bagged material for these tests. The gel time of Silikal R17AF was determined according to ASTM D 2471-71 (ASTM 1988g) by mixing a 400-g mass of the polymer system to a 400-mL plastic beaker. The slump and flow were determined according to ASTM C 143-78 (ASTM 1988h) and ASTM C 230-83 (ASTM 1988i), respectively.

Test Results

Compressive strength

54. Initially, 2-in. cubes of each material were cast for testing at both temperatures and curing times. The data from these tests were erratic and did not correlate with results expected from the manufacturers' reports. It appeared that the very small mass of a 2-in. cube did not allow consistent setting and strength gain at the colder temperature. For this reason, these data are not reported. Six-inch cubes of all three materials were tested at

the low temperatures given in Table 1. Strength values for all tests of compressive strength at cold temperatures are in Table 3.

55. Silikal R17AF was tested at temperatures of 20, 10, and 5 °F. At 20 °F the cubes were tested at 1-hr age. At 10 °F the cubes were tested at 2- and 3-hr ages. The material was too soft to remove from the mold after 1 hr at 10 °F. At 5 °F, the material was tested at the 2-hr age. In all of these tests, the Silikal R17AF achieved between 6,070 and 9,030 psi compressive strength (average of two cubes).

56. Pyrament 505 was tested at 1 and 4 hr after mixing, at temperatures of 40, 32, and 25 °F. At temperatures of 20 and 15 °F the cubes were tested at 2 and 4 hr, again because they could not be demolded at 1 hr at these temperatures. The data for Pyrament 505 in Table 3 also are the average of two cubes tested.

57. Set-45 was tested at ages of 2 and 4 hr at 40 °F. A test was planned at 1 hr at 32 °F, but the specimen was too soft to be removed from the mold. At the earlier age, Set-45 achieved a compressive strength of 460 psi. By a 4-hr age, the strength value was 1,550 psi (average of two cubes, Table 3).

58. Cylinders of each of the three materials were tested at room temperature using both wet and dry aggregate and at ages of 1 and 4 hr.

59. Table 4 gives both the compressive strengths and the elastic moduli of the three materials at room temperature using dry aggregate. The lowest moduli were recorded for Silikal R17AF, which had the highest compressive strengths. Likewise, the highest moduli occurred in the Set-45 material which had intermediate compressive strength values.

60. Figure A.1 of Appendix A compares the test results of all three materials at both 1 and 4 hr using dry aggregate. The highest strengths at both ages were obtained by the cylinders of Silikal R17AF; 6,010 psi at 1 hr and 7,420 psi at 4 hr. Pyrament 505 reached 1,210 psi in 1 hr and 3,120 psi after 4 hr. Set-45 had little change in compressive strength from 1 to 4 hr with 2,980 and 3,200 psi, respectively

61. Tests using wet aggregate indicated that lower compressive strengths were obtained with all three materials than when dry aggregate was used, as is illustrated in Figures A.2 and A.3. As with the dry aggregate, Silikal R17AF had the highest strengths at both ages; 2,570 at 1 hr and 3,510

at 4 hr. The lowest strengths at 1 hr were achieved by the Pyrament 505 cylinders, with 780 psi. Its strength at 4 hr was similar to that of Set-45 at both 1 and 4 hr (2,320 psi and 2,240 psi, respectively).

62. The moduli of elasticity and compressive strengths of the three materials at room temperature and using wet aggregate are listed in Table 5. As with dry aggregate, the Silikal R17AF had the lowest modulus at both ages. The moduli for each of the materials was lower when wet rather than dry aggregate was used. Set-45 again had the highest modulus at both ages.

Flexural strength

63. Tests of flexural strength were conducted on all three materials at room temperature using both wet and dry aggregates at 1 and 4 hr after mixing. In tests conducted at room temperature using dry aggregate, Silikal R17AF produced the highest flexural strengths at both ages by a wide margin. This material achieved 1,730 psi at 1 hr and 1,835 psi at 4 hr age. Pyrament 505 attained 230 psi at 1 hr and 465 psi at 4 hr. Set-45 was similar to Pyrament. Table 6 gives the results of these tests.

64. Table 7 indicates the results of tests of flexural strength conducted at room temperature using wet aggregate. As with the dry-aggregate tests, the Silikal R17AF gave the highest values at 1 hr, but overall the strengths were much more uniform. At 4 hr, the flexural strengths of Pyrament 505 and Silikal R17AF are comparable (375 and 390 psi, respectively). The flexural strength of Set-45 changed little, from 220 psi at 1 hr to 270 psi at 4 hr age.

65. Data from tests of flexural strength comparing values achieved with wet and dry aggregates are compared in Figures A.4 and A.5 (Appendix A).

66. Flexural strength also was determined for beam specimens prepared by mixing with dry aggregate but cast into standing water (wet environment). Each of the materials was tested at ages of 1 and 4 hr. Table 8 contains the data from these tests. All values decreased relative to standard tests with dry aggregate. The flexural strength of Silikal showed the largest percentage decrease, but was still higher than that of the other two materials.

Bond strength

67. The bond strength of each of the materials was determined using both wet and dry aggregates, and at cold temperatures. In tests conducted using dry aggregate at room temperature, both Silikal R17AF and Pyrament 505

developed bond strengths greater than 2,700 psi. Set-45 gave much lower bond strength, as shown in Table 9.

68. Table 10 shows the results obtained from using wet aggregate and casting the repair materials onto wet concrete surfaces. All three materials failed along the bond. Silikal R17AF failed at 600 psi and Set-45 at 1,260 psi. Pyrament 505 gave the strongest bonds in this condition, failing at 1,760 psi.

69. The cold temperature used was different for each material, as explained previously and summarized in Table 1. Cold-temperature tests were conducted at 15 °F for Pyrament 505, 45 °F for Set-45, and at 5 °F for Silikal R17AF. Both Pyrament 505 and Set-45 failed along the bond, at 1,260 and 590 psi, respectively. The Silikal R17AF test specimen failed through the concrete at 2,710 psi. Data are presented in Table 11.

70. Data for bond strength of materials prepared with dry and wet aggregate, and in cold conditions, are compared in Figure A.6.

Thermal contraction

71. Thermal contraction tests were conducted using wet and dry aggregate and at room temperature and cold temperatures for each of the three materials. The results of tests using dry aggregate are in Table 12. Pyrament 505 and Silikal R17AF contracted 0.028 and 0.119 percent, respectively. Set-45 expanded by 0.101 percent. Table 13 gives results of tests with wet aggregate. In these tests, the Set-45 expanded 0.126 percent, while the Pyrament 505 and Silikal R17AF contracted 0.018 and 0.150 percent, respectively.

72. Cold temperature contraction tests were conducted at the same cold temperatures as were other tests. As with wet and dry aggregate, Set-45 expanded in this test. Expansion in this instance was 0.145 percent. Both the Pyrament 505 and Silikal R17AF contracted, 0.030 and 0.162 percent, respectively. The results of these tests are detailed in Table 14.

Other tests

73. The times of initial and final setting were determined for Pyrament 505. The final time of set was determined for Set-45. Initial time of setting for Pyrament 505 was 20 min, and final time of setting was 27 min. Setting time for Set-45 was 8 min. Gel-time for Silikal R17AF was determined to be 10 min. The slump of Pyrament 505 as used in this study at room temperature was 8 in. These data are listed in Table 15.

Discussion

74. Each of the three materials evaluated has performance problems. The concrete based on SET-45 did not gain adequate strength to be tested at 1 or 2 hr after mixing, at temperatures lower than 40 °F, and does not bond well to existing concrete. As proportioned in this study, its cost (\$25 per ft^3) is about 10 times that of portland-cement concrete (PCC). Pyrament 505 gains strength more slowly than the other materials, achieving the lowest compressive and flexural strengths for room temperature and wet conditions at 1 hr. However, it continues to gain strength to 4 hr (and probably longer), and has outstanding bonding properties in both dry and wet conditions, at somewhat over three times the cost of PCC (\$8 per ft^3).

75. The other materials cannot approach the compressive strength achieved by Silikal R17AF in dry and cold conditions. But Silikal bonds poorly to wet surfaces or wet aggregate, at \$103 per ft^3, or about 40 times the cost of portland-cement. The Material Safety Data Sheets for Set-45 and Pyrament 505 are similar to those of portland-cement products, indicating no increased hazard to workers. Silikal is flammable and toxic, and the solvents required for cleanup are classified as hazardous wastes.

76. It is clear that no single criterion can be used to determine the suitability of a material for RRR spall repair. If the principal acceptance criteria is 4,000 psi at 1 hr in all conditions, as was discussed at the RRR Procedures Working Group Meeting in October 1989, then none of these materials meets it. Probably no fieldable, off-the-shelf product meets it.

77. The 4,000-psi figure apparently is based on the assumption that at 1 hr, the spall repair material must equal the compressive strength of the in-place undamaged concrete of an airfield. But it may not be necessary to equal this strength to support the first aircraft pass, or the first tens of passes. A lower strength may support this critical initial traffic, if other conditions are met (such as flexural strength and bond, discussed below), if the strength then continues to increase over the next few hours, to give the repaired area the durability to support sustained traffic. Silikal R17AF and Set-45 show very little change in measured strength between 1 and 4 hr, indicating that they achieve their ultimate strength value very early. The strength of Pyrament 505 increases notably during this time.

78. We had no bond-strength criteria from the Air Force when this report was prepared. Another study of the bond strength of a repair material to dry concrete at room temperature, with bond strength determined by the same modified slant-shear method used in our evaluation, reports bond strength between a latex-modified concrete and PCC after 14 days of careful curing (Knab and Spring 1989). These values were lower than those achieved by Pyrament 505 and Silikal R17AF in our study, after only 24 hr and with no careful curing. They are similar to the bond strength of Pyrament 505 proportioned with wet aggregate, cast against wet PCC, and tested at 24 hr (near 2,000 psi). Therefore, we assume that the bond strengths achieved by these two concretes in our study probably are higher far earlier than would be expected during routine concrete practice. Bond strength is not usually tested as early as 24 hr after casting, because no significant strength or bond is expected of conventional materials at such an early age.

79. A crater repair, which is by definition deep, can dissipate the heat evolved during hardening relatively slowly. It is held in place by its considerable mass, and by the physical interlocking between repair material and pavement and base course provided by random roughness on all surfaces of the crater. In contrast, a spall repair can be -- most probably will be -- shallow compared to the existing concrete, and have a very high surface-to-volume ratio. It is likely to experience more rapid cooling after hardening than is a deeper repair. Thus a spall is more likely to crack and contract when it cools, if it evolves a lot of heat during hardening and strength gain.

80. Relative to a crater repair, there is very little to hold the spall repair material in the hole, other than bonding between repair material and existing concrete. So in addition to having to bear load, a spall repair must have an adequate mechanism of staying in place. For this reason, a material that serves well for crater repair may not serve adequately for spalls. Unless adequate bonding is maintained, the spall repair material is apt to become a detached chunk of concrete moving freely in its custom-fit depression.

81. The ideal spall repair material would not heat up as it hardens, and thus would not be subjected to much thermal contraction as it cools. The peak exotherm values reported in Tables 12 and 13 show very little or no temperature increase for Pyrament 505 during the first 24 hr after mixing.

The data from thermal contraction for this material show essentially no volume change.

Recommendations

82. The currently fielded spall repair material, although it achieves very high strength, may not be the best choice for the RRR program. Its cost and toxicity are problems, as is the loss of bonding in wet conditions. The extraordinarily high strength it attains is really overkill, because it greatly exceeds the strength of the concrete in the runway being repaired. High strength being good does not necessarily mean that higher strength is better, unless other conditions are met.

83. We recommend a program to evaluate a candidate material for its ability to remain in the spall, with testing to begin at a flexural strength near 250 psi. We recommend development of standard criteria for bonding to existing concrete, flexural strength, and possibly thermal stability, for a spall repair material or system to be used in RRR. Exploring the potential for supporting traffic initially at a compressive strength lower than 4,000 psi, followed by strength gain and longer-term service, would be useful. Tests of mixing and placing characteristics and physical properties at a higher temperature -- maybe 100 °F -- also would be useful. Rapid-setting materials tested in previous studies were notorious for setting too fast to be placeable in hot weather.

84. With impending changes toward a more austere DOD budget, characteristics such as shelf life, versatility, and cost of the repair material will be more important.

85. If compressive strength of 4,000 psi at 1 hr is not used as the pass-fail criterion for a spall repair material, Pyrament 505 should be considered further. It gets close to the 250-psi value for flexural strength in 1 hr, shows thermal stability, bonds impressively to existing concrete in many conditions, is the least expensive of materials considered, is relatively safe to use, and is versatile. Because it gains strength rapidly between 1 and 4 hr, it may achieve adequate strength to support the first passes by aircraft very soon after 1 hr. We recommend evaluating the flexural and compressive strengths of Pyrament at closely spaced intervals following the

arbitrary 1-hr cut-off: 60, 75, and 90 min might serve. Considering all of its other positive characteristics, it is worth the effort to document how closely this material approaches the ability to support takeoff of the most likely light aircraft at some time soon after 1 hr. It does not seem reasonable to dismiss it totally because it does not equal the compressive strength of an all-purpose concrete runway within 60 min of mixing.

References

American Society of Testing Materials. 1988. "Standard Specification for Concrete Aggregates," Designation: C 33-86, 1988 Book of ASTM Standards, Vol 04.02, pp 9-15, Philadelphia, PA.

__________. 1988a. "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," Designation: C 39-86, 1988 Book of ASTM Standards, Vol 04.02, pp 19-23, Philadelphia, PA.

__________. 1988b. "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," Designation C 469-87a, 1988 Book of ASTM Standards, Vol 04.02, pp 233-236, Philadelphia, PA.

__________. 1988c. "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (using 2-in. or 50 mm Cube Specimens)," Designation: C 109-87, 1988 Book of ASTM Standards, Vol 40.01, pp 58-61, Philadelphia, PA.

__________. 1988d. "Standard Test Method for Flexural Strength of Concrete (using Simple Beam with Third-Point Loading)," Designation: C 78-84, 1988 Book of ASTM Standards, Vol 04.02, pp 31-33, Philadelphia, PA.

__________. 1988e. "Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete," Designation: C 882-87, 1988 Book of ASTM Standards, Vol 04.02, pp. 433-435, Philadelphia, PA.

__________. 1988f. "Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle," Designation: C 191-82, 1988 Book of ASTM Standards, Vol 04.01, pp 153-155, Philadelphia, PA.

__________. 1988g. "Standard Test Method for Gel Time and Peak Exothermic Temperature of Reacting Thermosetting Resins," Designation: D 2471-71 (Reapproved 1979), 1987 Book of ASTM Standards, Vol 08.02, pp 383-385, Philadelphia, PA.

__________. 1988h. "Standard Test Method for Slump of Portland Cement Concrete," Designation: C 143-78, 1988 Book of ASTM Standards, Vol 04.02, pp 85-86, Philadelphia, PA.

__________. 1988i. "Standard Specification for Flow Table for Use in Tests of Hydraulic Cement," Designation: C 230-83, 1988 Book of ASTM Standards, Vol 04.02, pp 126-130, Philadelphia, PA.

Boyer, J. P. and Kistler, C. 1982 (Jan). "Advanced Material Development for Repair of Bomb Damaged Runways," Designation: ESL-TR-82-14, USAF, AFESC, Tyndall AFB, FL.

Causey, F. E. 1983 (Dec). "Electronic Gage to Measure Care Shrinkage of Fast Setting Polymeric and Other Cementitious Materials," Designation: GR-83-10; US Department of Interior, Denver, CO.

Collum, C. E., Denson, R. H., and Hoff, G. C. 1978 (Mar). "Repair and Restoration of Paved Surfaces," Designation: TR C-78-2, Report 1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Knab, L. I. and Spring, C. B. Summer 1989. "Evaluation of Test Methods for Measuring the Bond Strength of Portland Cement Based Repair Materials to Concrete," Designation: CCAGDP, Vol 11, No. 1, pp 3-14, Gaithersburg, MD.

Table 1

Time, Temperature, Compressive Strength Relations

Product	1 hr °F psi	2 hr °F psi	3 hr °F psi
Silikal	20 (6970)	5 (7180)	- -
Pyrament	25 (820)	20 (1420)	15 (1660)
Set-45	- -	40 (460)	40 (1550)

Table 2

Mixing Time Required for Concretes and Ambient and Minimum Test Temperatures

Material	Mixing Time, Minutes At 73 °F	Mixing Time, Minutes At Low Temperature (°F)
Silikal	2	2 (5)
Pyrament 505	6	2 (15)
Set-45	2	2 (40)

Table 3

Compressive Strength, Cold Temperatures, 6-in. Cubes

Material	Age, hr	Temperature, °F	Compressive Strength, psi
Pyrament 505	1	40	1,450
Pyrament 505	4	40	2,630
Pyrament 505	1	32	800
Pyrament 505	4	32	2,250
Pyrament 505	1	25	820
Pyrament 505	4	25	1,810
Pyrament 505	2	20	1,420
Pyrament 505	4	20	1,750
Pyrament 505	2	15	1,550
Pyrament 505	4	15	1,660
SET-45	2	32	Too Soft
SET-45	2	40	460
SET-45	4	40	1,550
Silikal	1	20	6,970
Silikal	1	10	Too Soft
Silikal	2	10	8,360
Silikal	3	10	9,030
Silikal	2	5	7,180

Table 4

Compressive Strength, 73 °F, Dry Aggregate

Material	Age, hr	Compressive Strength, psi	Modulus of Elasticity, millions of psi
Pyrament 505	1	1,210	3.45
Pyrament 505	4	3,120	4.00
SET-45	1	2,980	3.95
SET-45	4	3,200	4.65
Silikal R17AF	1	6,010	1.35
Silikal R17AF	4	7,420	2.00

Table 5

Compressive Strength, 73 °F, Wet Aggregate

Material	Age, hr	Compressive Strength, psi	Modulus of Elasticity, millions of psi
Pyrament 505	1	780	2.60
Pyrament 505	4	2,180	3.50
SET-45	1	2,320	3.20
SET-45	4	2,250	4.55
Silikal R17AF	1	2,570	0.50
Silikal R17AF	4	3,510	0.90

Table 6

Flexural Strength, 73 °F, Dry Aggregate

Material	Age, hr	Flexural Strength, psi
Pyrament 505	1	230
Pyrament 505	4	465
SET-45	1	275
SET-45	4	320
Silikal R17AF	1	1,730
Silikal R17AF	4	1,835

Table 7

Flexural Strength, 73 °F, Wet Aggregate

Material	Age, hr	Flexural Strength, psi
Pyrament 505	1	175
Pyrament 505	4	375
SET-45	1	220
SET-45	4	270
Silikal R17AF	1	355
Silikal R17AF	4	390

Table 8

Flexural Strength, Wet Environment

Material	Age, hr	Flexural Strength, psi
Pyrament 505	1	195
Pyrament 505	4	365
SET-45	1	205
SET-45	4	300
Silikal R17AF	1	1,140
Silikal R17AF	4	1,345

Table 9

Bond Strength, 73 °F, Dry Aggregate and Concrete

Material	Bond Strength, psi	Type of Failure
Pyrament 505	2,720	Bond failure
SET-45	1,200	Bond failure
Silikal R17AF	2,760	Concrete failure

Table 10

Bond Strength, 73 °F, Wet Aggregate and Concrete

Material	Bond Strength, psi	Type of Failure
Pyrament 505	1,760	Bond failure
SET-45	1,260	Bond failure
Silikal R17AF	600	Bond failure

Table 11

Bond Strength, Cold Temperature

Material	Temperature, °F	Bond Strength, psi	Type of Failure
Pyrament 505	15	1,260	Bond failure
SET-45	45	590	Bond failure
Silikal R17AF	5	2,710	Concrete failure

Table 12

Contraction, 73 °F, Dry Aggregate

Material	Peak Exotherm, °F	Contraction, %
Pyrament 505	27	0.028
SET-45	78	0.105*
Silikal R17AF	74	0.119

* Expansion

Table 13

Contraction, 73 °F, Wet Aggregate

Material	Peak Exotherm, °F	Contraction, %
Pyrament 505	19	0.018
SET-45	76	0.126*
Silikal R17AF	69	0.150

* Expansion

Table 14

Contraction, Cold Temperature

Material	Temperature, °F	Peak Exotherm, °F	Contraction, %
Pyrament 505	15	0	0.030
SET-45	45	19	0.145*
Silikal R17AF	5	45	0.162

* Expansion

Table 15

Time of Setting

	Pyrament 505	SET-45
Initial time of setting, minutes	20	
Final time of setting, minutes	27	8

Gel-time for Silikal R17A5, ------------------------------ 10 minutes
400 g mass, 73 °F

Slump of Pyrament 505 ------------------------------------- 8 in.

APPENDIX A
FIGURES FROM BRIEFINGS

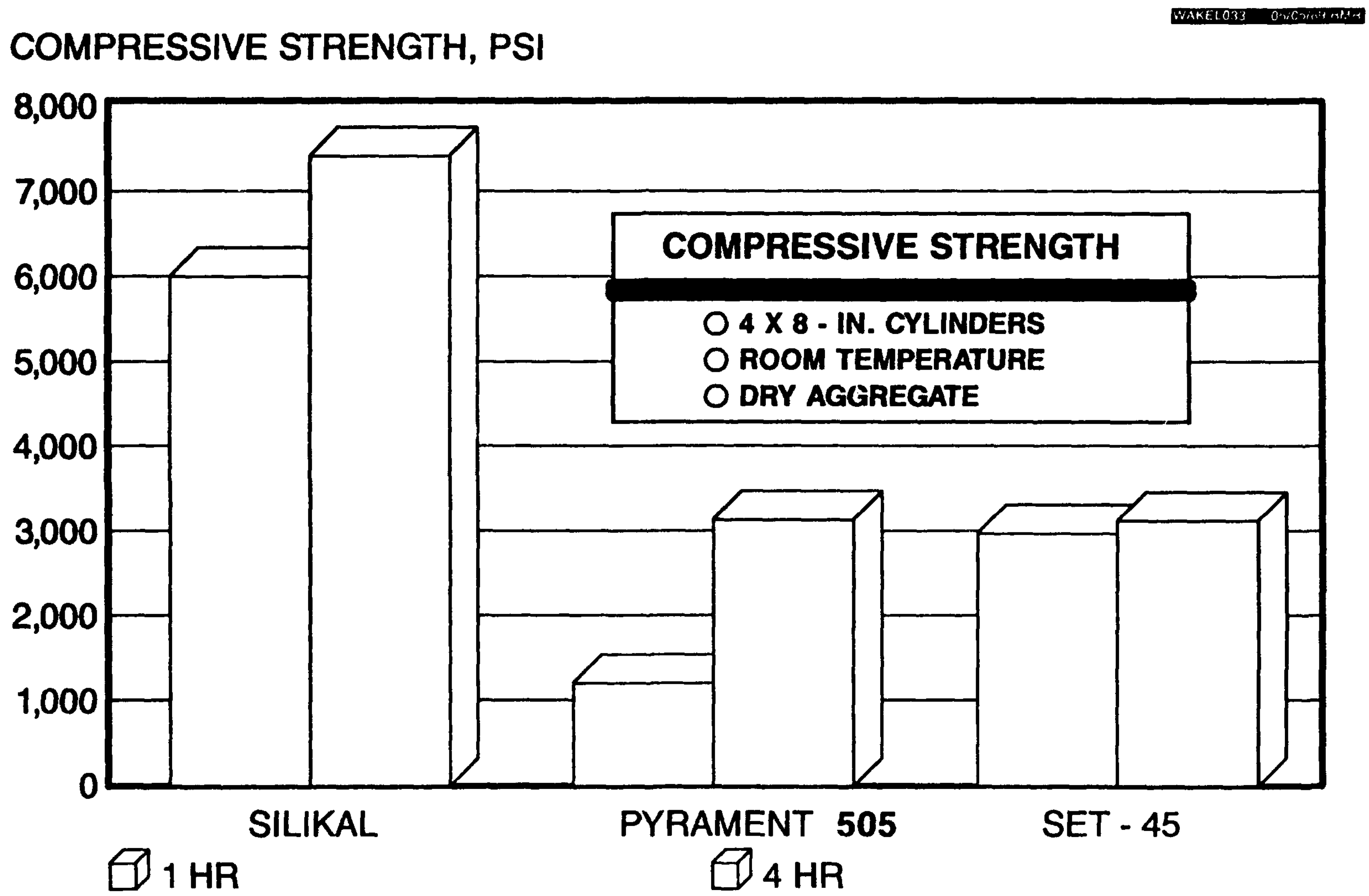

Figure A.1. Compressive Strength, 4- by 8-in. Cylinders (Dry Aggregate)

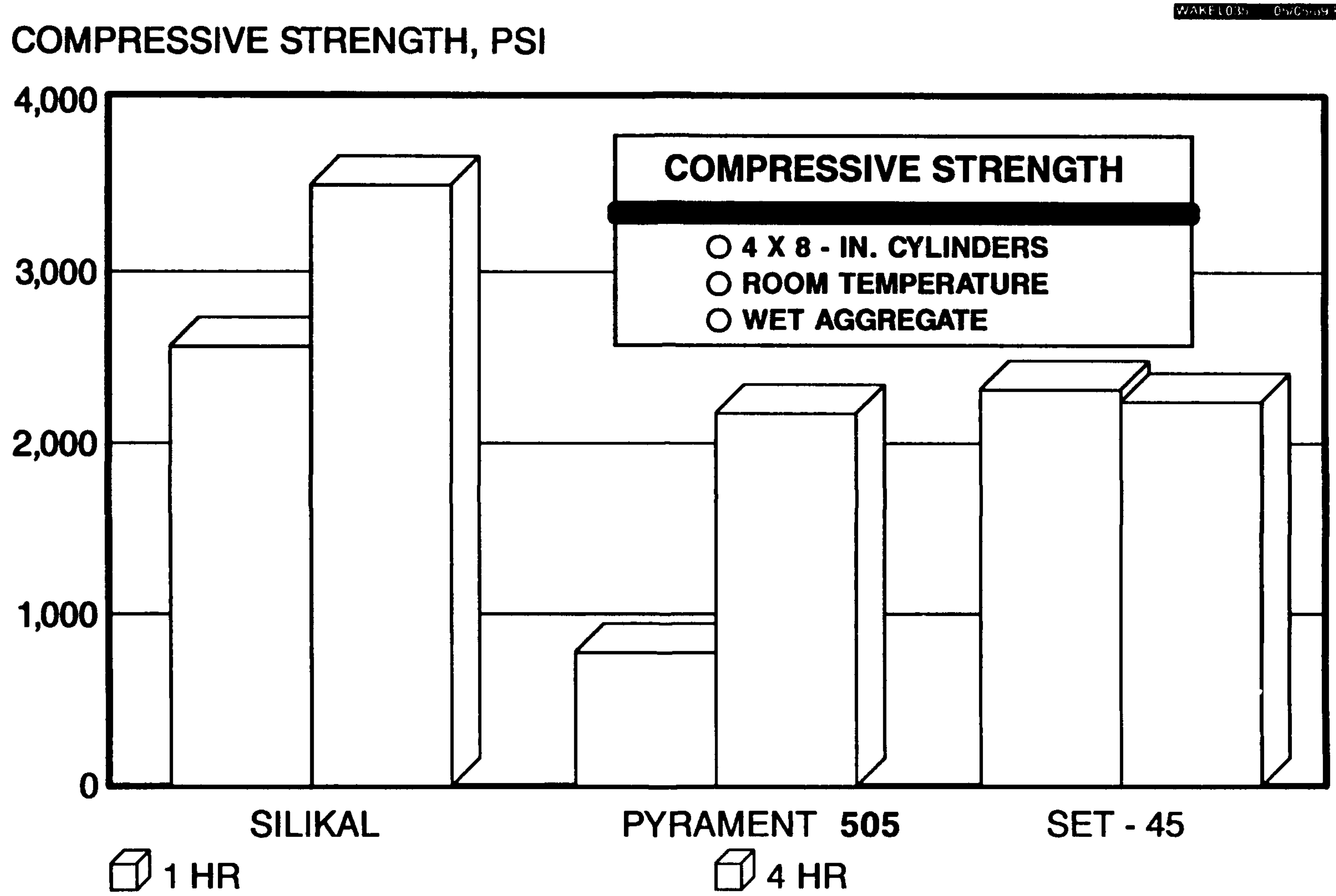

Figure A.2. Compressive Strength, 4- by 8-in. Cylinders (Wet Aggregate)

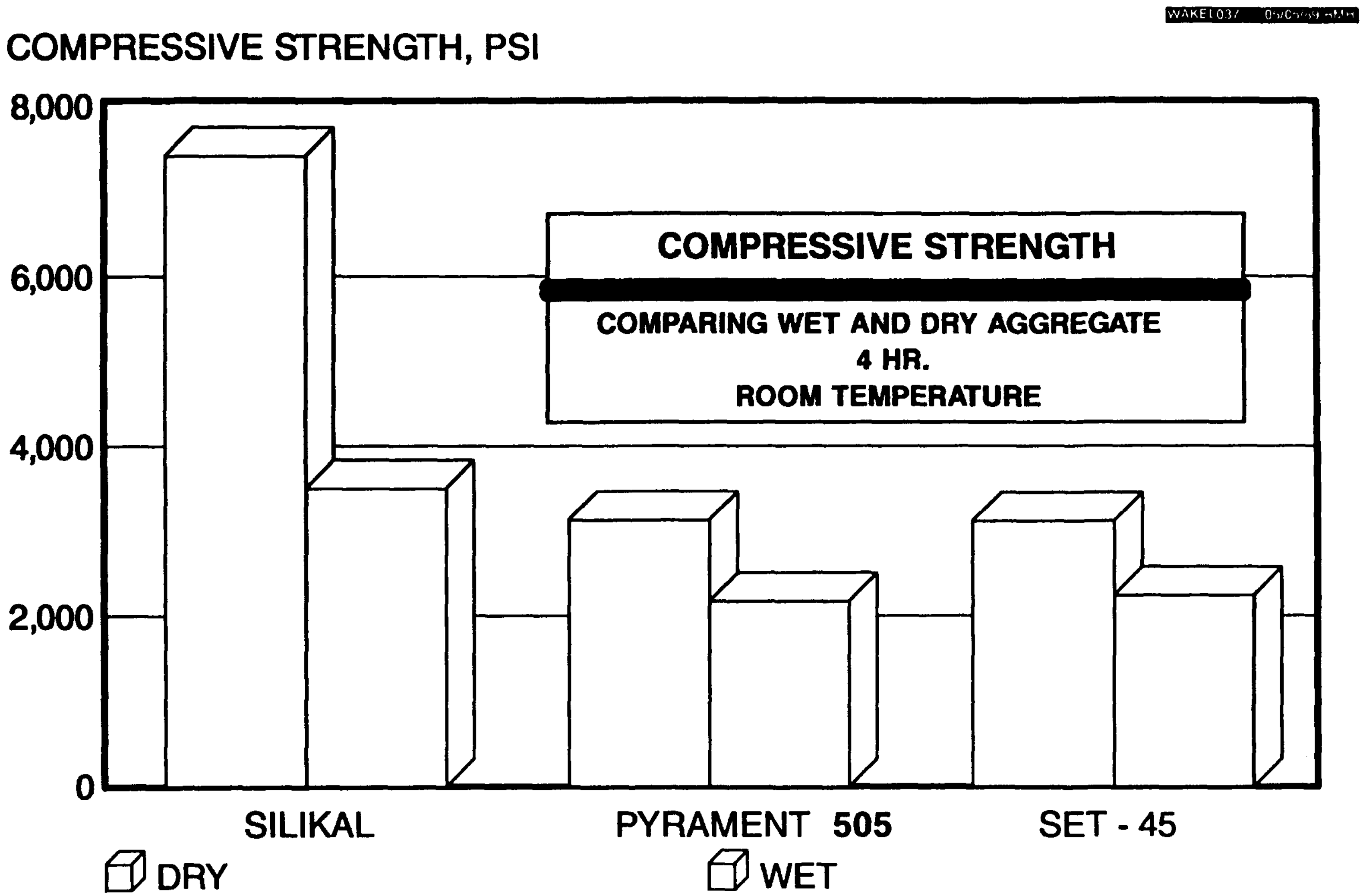

Figure A.3. Compressive Strength, Comparing Wet and Dry Aggregate (4 hr)

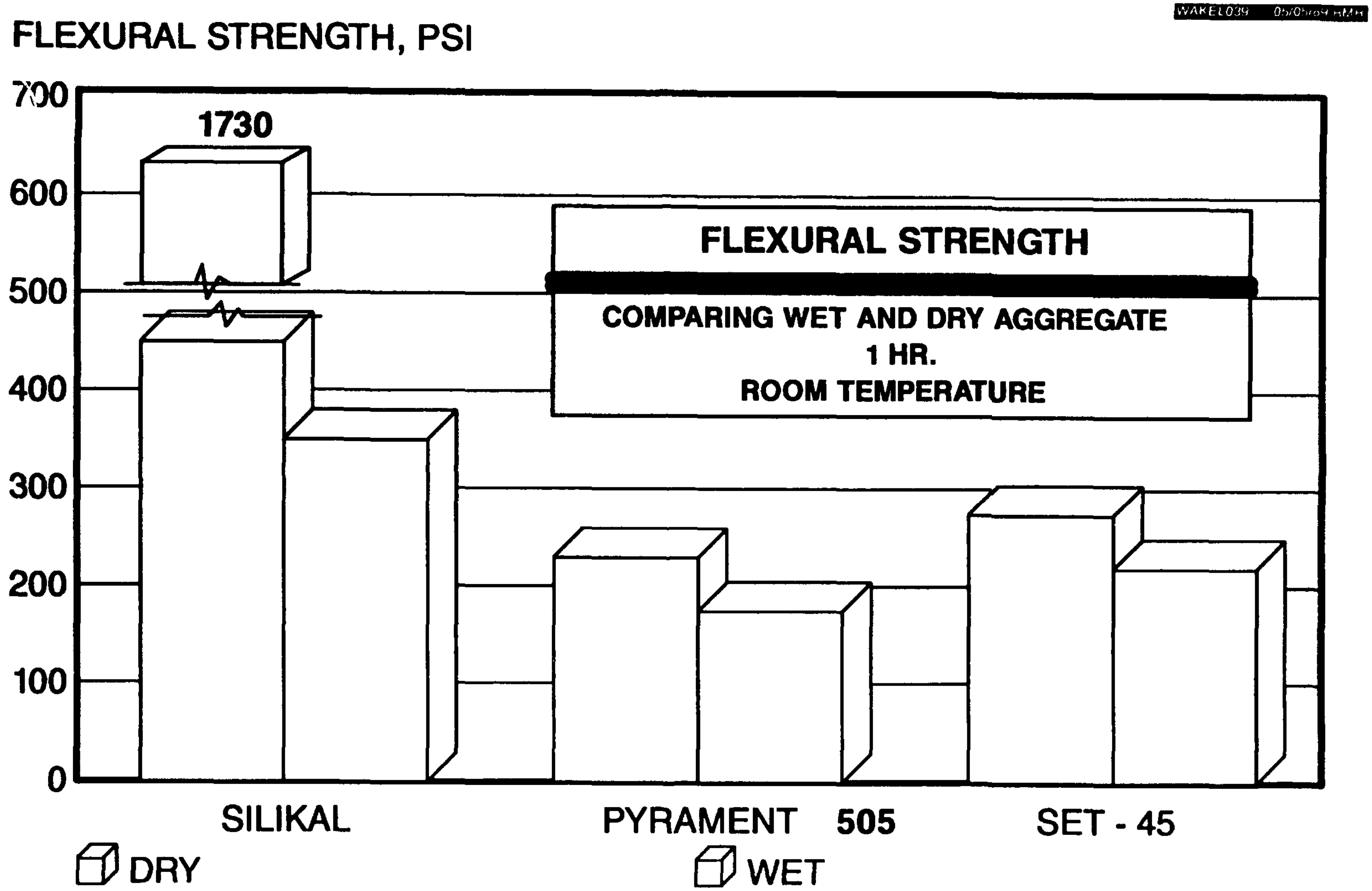

Figure A.4. Flexural Strength, Comparing Wet and Dry Aggregate (1 hr)

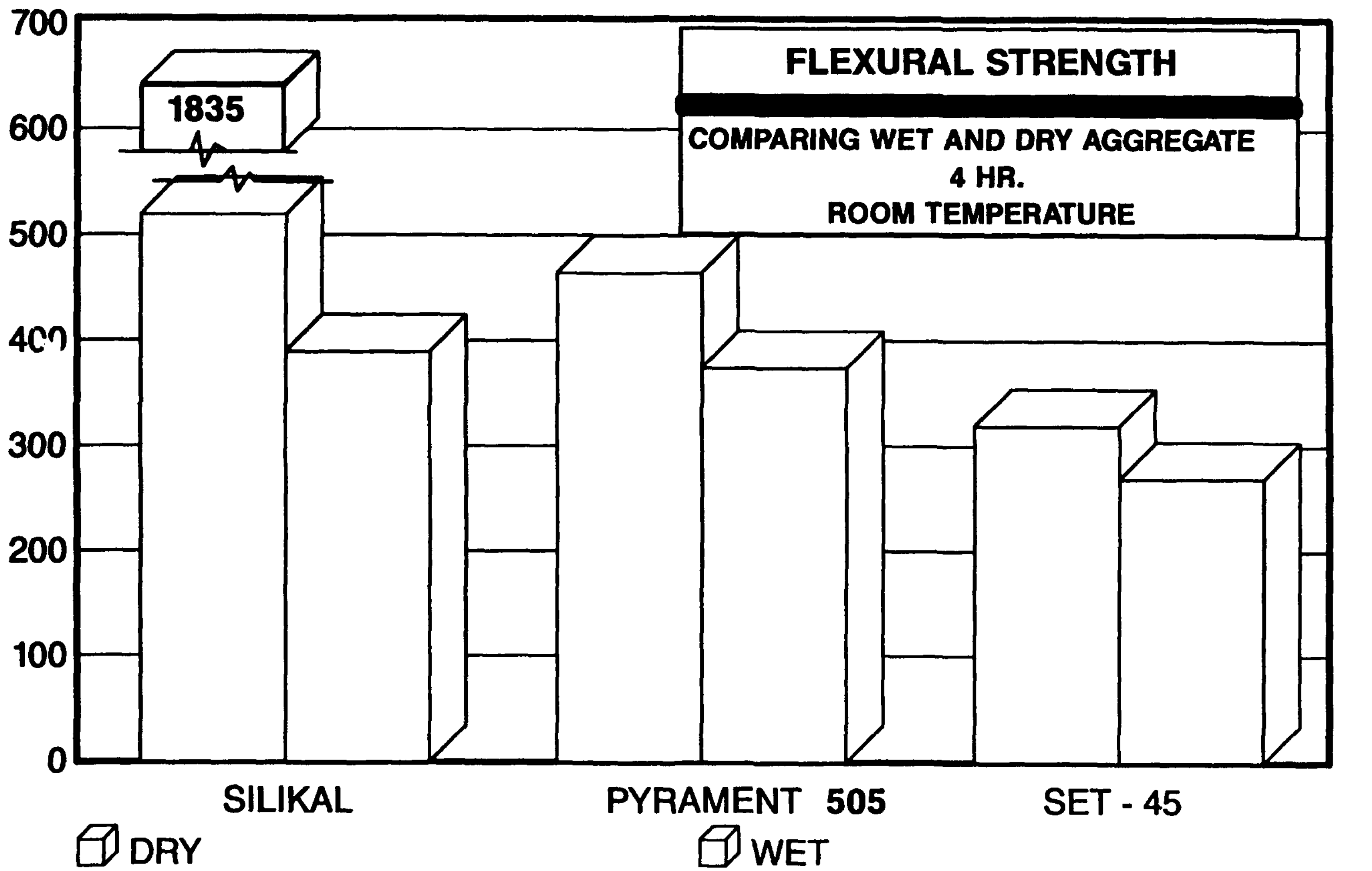

Figure A.5. Flexural Strength, Comparing Wet and Dry Aggregate (4 hr)

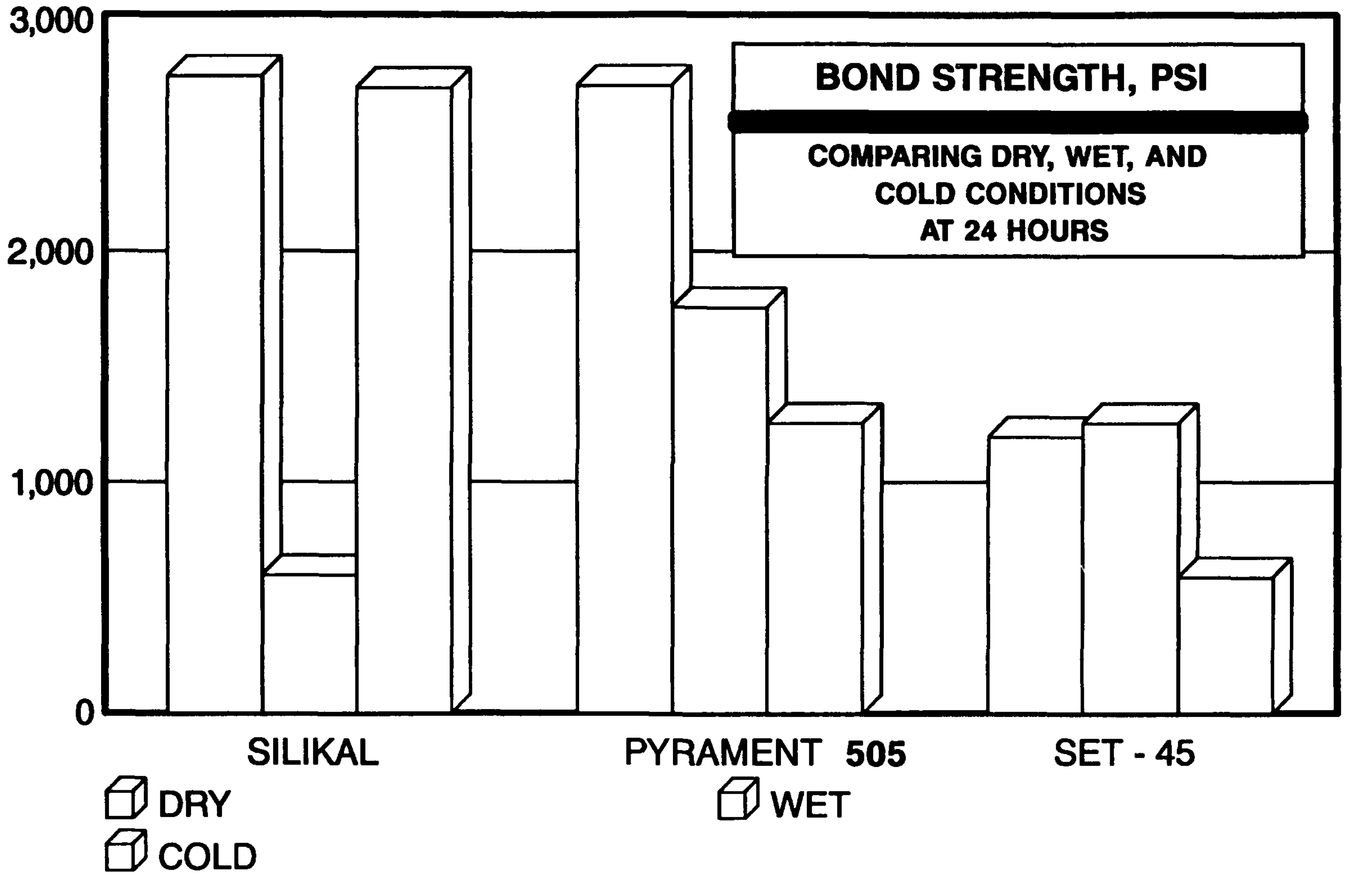

Figure A.6. Bond Strength, Comparing Dry, Wet, and Cold Conditions at 24 hr

APPENDIX B
WORD SLIDES FROM BRIEFINGS

EVALUATION OF QUICK SETTING CEMENTS

OBJECTIVE

EVALUATE COMMERCIALLY AVAILABLE OFF-THE-SHELF RAPID SETTING CEMENTS FOR USE IN RAPID AIRFIELD REPAIR

EVALUATION OF QUICK SETTING CEMENTS

MATERIALS

- SILIKAL
- PYRAMENT 505
- SET 45

EVALUATION OF QUICK SETTING CEMENTS

PROPERTIES TO BE EVALUATED

- FLEXURAL STRENGTH
- COMPRESSIVE STRENGTH
  - CUBES
  - CYLINDERS
- BOND STRENGTH
- THERMAL SHRINKAGE
- WET ENVIRONMENT
- SLUMP
- FLOW
- SET TIME

EVALUATION OF QUICK SETTING CEMENTS

COMPRESSIVE STRENGTH (2-IN CUBES)

- ASTM C 109-87
- DRY AGGREGATE
- TWO TEMPERATURES
- TWO CURING TIMES

EVALUATION OF QUICK SETTING CEMENTS

COMPRESSIVE STRENGTH (4in x 8in CYLINDERS)

- ASTM C 39-86
- WET/DRY AGGREGATE
- ONE TEMPERATURE
- TWO CURING TIMES
- STATIC MODULUS OF ELASTICITY (ASTM C 469-87)

WAKEL042

COMPRESSIVE STRENGTH, PSI

	1 HOUR	
	DRY	WET AGGREGATE
SILIKAL	6010	2570
PYRAMENT 505	1210	780
SET - 45	2980	2320

EVALUATION OF QUICK SETTING CEMENTS

FLEXURAL STRENGTH

- ASTM C 78-84
- WET/DRY AGGREGATE
- ONE TEMPERATURE
- TWO CURING TIMES

WAKE1041

FLEXURAL STRENGTH, PSI

	WET AGGREGATE	
	1	4 HOURS
SILIKAL	350	390
PYRAMENT 505	175	375
SET - 45	220	270

EVALUATION OF QUICK SETTING CEMENTS

WET ENVIRONMENT

- FLEXURAL BEAM SPECIMENS
- MOLD HALF-FULL OF WATER
- NO TAMPING OR VIBRATION
- WET AGGREGATE
- ONE TEMPERATURE (73°F)
- ONE OR TWO CURING TIMES
- ASTM C 78-84

WAKEL054 10/11/89 BMH

FLEXURAL STRENGTH, PSI

4 HOURS, 73 F

	DRY AGGREGATE	STANDING WATER	WET AGGREGATE
SILIKAL	1835	1345	390
PYRAMENT	465	365	375
SET - 45	320	300	270

WAKEL040

ALL STRENGTH VALUES

- STRENGTH INCREASE FROM 1 TO 4 HOURS IS GREATEST FOR PYRAMENT 505
- STRENGTH DECREASE FROM DRY TO WET AGGREGATE IS GREATEST FOR SILIKAL

BRABS033 04/05/89 CBC

EVALUATION OF
QUICK SETTING CEMENTS

THERMAL SHRINKAGE

- REF: BUR OF RECLAMATION REPORT NO. CR 83-10
- WET/DRY AGGREGATE
- TWO TEMPERATURES

EVALUATION OF QUICK SETTING CEMENTS

BOND STRENGTH

- ASTM C 882-87
- WET/DRY AGGREGATE
- TWO TEMPERATURES
- ONE CURING TIME (24 HR)

WAKEL050 10/11/89

BOND STRENGTH, PSI

24 HOURS

	DRY[1]	WET[1]	COLD[2]
SILIKAL	2760	600	2710
PYRAMENT	2720	1760	1260
SET-45	1200	1260	590

1 - AGGREGATE AND CONCRETE SURFACE

2 - MINIMUM TEMP. FOR EACH MATERIAL

EVALUATION OF QUICK SETTING CEMENTS

ADDITIONAL TESTS

- SLUMP ASTM C 143-78
- FLOW ASTM C 230-83
- SET TIME ASTM C 403-85

PERFORMANCE PROBLEMS

SILIKAL

- BONDING AND FLEXURAL STRENGTH DECREASE DRASTICALLY WHEN WET
- TOXIC

PYRAMENT 505

- LONGER TIME TO GAIN STRENGTH

SET - 45

- LIMITED TO TEMPERATURE ABOVE FREEZING
- LOW FLEXURAL STRENGTH

APPENDIX C
RESEARCH PROJECT PLAN

CEWES-SC-MC 4 April 1989

RESEARCH PROJECT PLAN NO. 89-20 JOB NUMBER: RD9G628SC170001

SUBJECT: Evaluation of Rapid-Setting Concretes for Airfield Spall Repair

1. Principal Investigator for CTD:

    a. Lillian D. Wakeley

    b. Materials and Concrete Analysis Group

    c. Ext. 3215

2. Sponsor and Authority. Air Force Engineering and Services Center (HQ AFESCE/YE), Military Interdepartmental Purchase Request (MPIR) N88-83, to W. N. Brabston, Pavement Systems Division, GL. Dr. Wakeley serves as liaison between PSD and CTD for this project.

3. Objective. Evaluate three commercially available, off-the-shelf, rapid-setting concrete materials (Silikal R-17, Pyrament 505, and Set 45 Repair Grout) for their application to repairing airfield spalls. The principal criteria are high early strength, performance over a range of temperatures and wet environment, and bond to existing pavement.

4. Background. The USAF currently uses Silikal to repair spalls or small craters in airfields under wartime conditions. Silikal is a methyl methacrylate-based polymer concrete which is used because it sets and gains strength rapidly over a wide range of temperatures. However, it has some undesirable characteristics: it is flammable, costly, and workers must wear respirators and other protective gear. The placement and performance characteristics of Silikal are reported in ESL-TR-82-04, "Methacrylate Polymer Concrete for Bomb Damage Repair" (August 1982). Because Silikal is currently used by the Air Force, it will be used as a baseline material to which other

materials will be compared and will be subjected to the same tests and analyses.

5. Task Definitions. All laboratory work, specimen preparation, and testing will be accomplished in the CTD.

a. Chemistry Unit. Mr. Husbands and Mr. White will coordinate all phases of testing and preparation of test specimens, and obtain materials and data available from manufacturers.

(1) Prepare all bond strength test specimens. Specimens will be prepared according to the method given in ASTM C 882-87, slant shear test. The method will be modified to bond the rapid-setting concrete directly to existing concrete using 4- by 8-in. cylinders. The recipient concrete will be at least 28 days old (moist cure) and have a compressive strength of at least 5,000 psi. Bonding surfaces will be prepared by light sandblasting. Three test specimens for each material will be prepared for testing at two temperatures and two conditions. The two temperatures will be 73°F and a low temperature to be established, and the two conditions will be wet and dry aggregate. Ms. Judy Tom will assist with preparation and handling of specimens.

(2) Obtain aggregate which shall be river-run quartz, conforming to the grading requirement of ASTM C 33-86 size No. 6 or 67. Saturate aggregate in suitable container with water for mixing materials requiring a wet aggregate condition.

(3) Determine low temperature test condition and time of test by testing cubes at various low temperatures or from minimum temperature furnished by manufacturer. This work will be coordinated with the Cement and Pozzolan Unit as necessary.

b. Concrete and Grout Unit. Will be responsible for the following tests:

(1) Flexural strength. Flexural beams 3-1/2 by 4-1/2 by 16 in. will be fabricated and tested in accordance with ASTM C 78-84. Two test specimens for each material will be tested for each age and condition. The two test ages will be 1 and 4 hours. The early test age may have to be increased, depending on when the specimens can be stripped from the molds. The two conditions will be dry and wet aggregates. All test specimens will be fabricated and tested at 73°F. The Chemistry Unit will furnish the materials and mixture proportions.

(2) Performance in a wet environment. Flexural beam molds will be sealed with wax or an appropriate sealing compound to prevent water leakage. The molds will be filled one-half full of water and the mixed concrete will then be placed in the mold as quickly as possible, the molds overfilled, and the concrete screeded off (no tamping, vibrating, or other ideal compaction). These beams will be tested according to ASTM C 78-84. Two test specimens for each material will be tested at 1 and 4 hours. The early test age may have to be increased depending on when the specimens can be stripped from the molds.

c. Cement and Pozzolan Unit. Compressive strength of 2-in. cubes will be determined according to the method given in ASTM C 109-87. Three test specimens will be tested for each age and temperature. The two test ages will be 1 and 4 hours. The two temperatures will be 73°F and a low temperature to be established. The test ages for the low temperature will have to be increased if the material does not achieve adequate strength to be tested at these ages. Specimen molds, aggregate, and material will be conditioned to the test temperature. See also item 5a(3).

d. Materials and Concrete Analysis Group. This group will be responsible for the following tests:

(1) Compressive strength and static modulus of elasticity. The compressive strength of 4- by 8-in. cylinders will be determined in accordance

with ASTM C 39-86. Static modulus of elasticity also will be determined in these tests according to ASTM C 469-87. Three test specimens for each material will be tested at two ages and conditions (dry and wet aggregate). The cylinders will be fabricated by the Chemistry Unit. The two ages will be determined by testing specimens cast from the materials before other tests are started to determine the necessary time for preparing and testing specimens made from each material. Assistance from or transfer of tasks to the Concrete and Grout Unit will be coordinated as necessary with Messrs. Ragan and Neeley.

(2) Thermal shrinkage. The thermal shrinkage will be monitored for 24 hours using a DuPont shrinkage gauge as described in Bureau of Reclamation Report No. GR-83-10. Two thermal shrinkage measurements will be made for each material at two temperatures and conditions. The two temperatures will be 73°F and a low temperature to be established, and the two conditions will be dry and wet aggregate. Mixing instructions and materials will be furnished by the Chemistry Unit. Tests will be performed by Mr. Causey.

(3) Bond strength. Cylinders prepared for bond strength will be tested for bond strength 24 hours after casting according to ASTM C 882-87.

6. People and Responsibilities:

a. Mr. Husbands and Dr. Wakeley will be responsible for coordination of work and will prepare appropriate reports, in conjunction with Dr. Brabston. All participants will provide data to Mr. Husbands.

7. Schedule and Funding. Funding for this project is 70K in SL. Funds will carry over into FY90. Scheduling for the work is as follows:

a. Start work: 21 February 1989.

b. Tests to be completed: 1 July 1989.

c. Draft technical report: 18 August 1989.

d. Final report 3 months after draft technical report has been reviewed by AFESC and returned to WES.

KENNETH L. SAUCIER
Chief, Concrete Technology Division
Structures Laboratory

CF:
Mather
Ballard
Saucier
Stowe
Wakeley
Husbands
White
Causey
Poole
Judy Tom
Ragan
Neeley
Chapman

APPENDIX D
MATERIALS PROPERTIES AS REPORTED BY MANUFACTURERS

Materials Properties

Silikal R17AF Polymer Concrete. The properties of R17AF polymer concrete reported by the manufacturer are listed below:

Property	Test Method	Test Result
Compressive strength, psi	ASTM C109	9,200
	ASTM C39	7,800
Compressive modulus, psi $\times 10^6$	ASTM C469	1-2
Flexural strength, psi	ASTM D790	2,800
Linear shrinkage, Maximum, %	(24 hr Silikal Method)	0.2
Coefficient of Thermal Expansion in/in./°F $\times 10^{-6}$	ASTM C531	18
Pot Life (minutes at 68°F)		15-20
Curing Time (hours at 68°F)		1

Pyrament 505. The properties of Pyrament 505 mortar and mortar extended with 1/2-in. gravel reported by the manufacturer are listed below:

	Mortar	Mortar and Gravel
Pyrament 505 (lbs)	50.0	50.01/2-in.
Gravel (lbs)	----	50.0
Water (lbs)	4.8	4.8
Yield (cu ft)	0.4	0.7
Consistency (15 minutes)	ASTM C109-86	ASTM C143-78
	105 percent	3 in.
Time of Setting Final (minutes)	ASTM C266-86	ASTM C403-85
	30	30
Compressive strength (psi)	ASTM C109-86	ASTM C39-86
2 hours	2,500	2,500
3 hours	3,500	2,500
1 day	6,000	5,500
7 days	10,000	9,000
Flexural strength (psi)	ASTM C293-79	ASTM C293-79
3 hours	600	400

(Continued)

	Mortar	Mortar and Gravel
1 day	1,000	700
7 days	15,001	900
Modulus of Elasticity (psi)	ASTM C469-83	ASTM C469-83
28 days	----	5.5×10^6
Freeze/Thaw Durability	ASTM C666-84	ASTM C666-84
300 cycles		
Durability Factor	96	96

Set-45. The properties of Set-45 reported by the manufacturer are listed below:

Property	Test Method	Test Results
Compressive strength, psi	ASTM C109-86	
1 hour		2,000
3 hours		5,000
24 hours		6,000
3 days		7,000
28 days		9,000
Flexural strength, psi	ASTM C78-84	
3 hours		600
24 hours		900
7 days		1,000
Time of setting, initial, minutes	ASTM C-266	15
Time of setting, final minutes	ASTM C-266	20
Expansion, %	CRD-589	
1 hour		0.19
24 hours		0.23
7 days		0.23
Freeze/thaw durability	ASTM C666-84	
300 cycles		
Durability factor		79.8

(Continued)

Property	Test Method	Test Results
Scaling/resistance to de-icing chemicals	ASTM C-672	

No. of Cycles	Rating	Condition of Surface
5	0	no scaling
25	0	no scaling
50	1:5	slight scaling

APPENDIX E
MATERIAL SAFETY DATA SHEETS

Silikal®

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255 Hathaway Drive
Stratford, Connecticut 06497 USA
Tel.: (203) 377-5500 • Fax: (203) 377-5329

HAZARD RATING
4 = EXTREME
3 = HIGH
2 = MODERATE
1 = SLIGHT
0 = INSIGNIFICANT
* = CHRONIC HEALTH HAZARD – SEE SECTION IV

Fire: 3 | Reactivity: 2 | Health | Special

MATERIAL SAFETY DATA SHEET

PRODUCT NAME	CHEMICAL FAMILY
Silikal R17 Liquid Component	Methacrylate Ester Monomer
CHEMICAL NAME & SYNONYMS	**FORMULA**
Acrylic Resin	$C_5H_8O_2$

INGREDIENTS

CAS *	COMPONENTS	WEIGHT %	TWA/TLV
86-62-6	Methyl Methacrylate	‹92.0	100 ppm TWA (Typ.)
	Polyfunctional Acrylic Ester	T	400 ppm TWA
N/A	Refined Aliphatic Hydrocarbons	‹8.0	5 mg/M³ TWA
	Tert. Amine based on P-Toludine	‹1.8	N.E.
	Alkylated Cresol	T	10 mg/M³ TWA

PHYSICAL DATA

APPEARANCE — ODOR			VISCOSITY
Clear mobile liquid; acrid fruity odor			1 cps at 68°F
MELTING OR FREEZING POINT	**BOILING POINT**	**VAPOR PRESSURE (mm Hg)**	**VAPOR DENSITY (AIR=1)**
−54°F (−48°C)	214°F (101°C)	40 mm Hg	3.5 (Heavier than air)
SOLUBILITY IN WATER	**PERCENT VOLATILE (BY WEIGHT)**	**SPECIFIC GRAVITY (WATER = 1)**	**EVAPORATION RATE (BUTYL ACETATE = 1)**
Moderate	92	0.934	About equal to BA

FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	AUTO IGNITION TEMPERATURE	LOWER EXPLOSION LIMIT (%)	UPPER EXPLOSION LIMIT (%)
49°F (30.6°C) Setaflash CC	815°F (435°C)	2.12	12.5

EXTINGUISHING MEDIA
☒ FOAM ☐ "ALCOHOL" FOAM ☒ CO_2 ☒ DRY CHEMICAL ☒ WATER FOG ☐ OTHER

SPECIAL FIRE FIGHTING PROCEDURES
Wear MESA/NIOSH approved self-contained breathing apparatus. Fight fires from safe distance or protected area. Use cold water spray to cool fire-exposed containers of Methyl Methacrylate.

UNUSUAL FIRE AND EXPLOSION HAZARDS
Vapors may travel to source of ignition and flash back. Heat, aging, or contamination may lead to polymerization and/or violent rupture of sealed containers. Cool warm or bulging containers to ambient temperature with water stream from safe distance. Then wear eye and face protection and protective clothing to carefully remove bung to vent pressure build-up. Reclose and dispose of container.

HEALTH HAZARD DATA

RECOMMENDED TWA (MAXIMUM TIME - WEIGHTED - AVERAGE CONCENTRATION FOR AN 8-HOUR WORK PERIOD)
TWA = 100 PPM THRESHOLD LIMIT VALUE (TLV) = 300 PPM (Based on Methyl methacrylate)

EFFECTS OF OVEREXPOSURE
High vapor concentration can cause irritation to eyes, skin, and respiratory system. Extended exposure can lead to headache, nausea, drowsiness, and unconsciousness. Direct liquid contact with eyes can cause severe irritation and possible corneal damage. Prolonged skin contact with liquid can cause irritation and skin rash.
DO NOT WEAR CONTACT LENSES WHEN USING THIS PRODUCT.

EMERGENCY AND FIRST AID PROCEDURES
INHALATION: Move subject to fresh air. Give oxygen if breathing is difficult; artificial respiration if breathing has stopped.
CONTACT: Flush eyes with plenty of water for at least 15 minutes and get prompt medical attention; wash skin thoroughly with soap and water; remove and wash clothing before reuse.
INGESTION: If swallowed and victim is conscious, induce vomiting by giving two glasses of water for drink and sticking finger in throat. Immediately call a physician. Never induce vomiting or give anything by mouth to an unconscious person.

*NOTE: CAS No. where not listed is proprietary. However, all materials are TSCA listed.

REACTIVITY DATA

STABILITY	CONDITIONS TO AVOID
Stable	Heat and ignition sources, aging
POLYMERIZATION	**CONDITIONS TO AVOID**
May occur	Elevate temperatures, oxygen-free atmosphere, contamination

INCOMPATABILITY (MATERIALS TO AVOID)
Reducing agents, oxidizing agents (e.g., rust), solid polymeric particles (e.g., cured materials)

HAZARDOUS DECOMPOSITION PRODUCTS
Thermal decomposition may yield water, oxides of carbon, or acid fumes

SPILL OR LEAK PROCEDURE

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
Evacuate area. Eliminate ignition sources. Wear protective clothing and overshoes and MESA/NIOSH approved respirator for vapor concentrations encountered. Dike spill with inert material (sand, earth, Fuller's earth, etc.). Transfer liquid and solid diking materials with non-sparking shovels to separate containers for disposal. KEEP SPILL OUT OF ALL SEWERS AND OPEN BODIES OF WATER. Follow emergency and first aid procedure

WASTE DISPOSAL METHOD
Incinerate liquid in approved equipment. Landfill contaminated diking material, after allowing liquid to evaporate to reduce flash point to a safe level, according to current local, state, and federal regulations.

SPECIAL PROTECTION INFORMATION

VENTILATION TYPE	PROTECTIVE GLOVES
For indoor operations — explosion-proof mechanical ventilation to keep vapors below TWA and LEL.	Impervious (e.g., neoprene)
RESPIRATORY PROTECTION Wear MESA/NIOSH approved chemical cartridge respirator for organic vapors where exposure limits are exceeded.	**EYE PROTECTION** splashproof glasses (ANSI Z87.1, 1979)

OTHER PROTECTIVE EQUIPMENT
Protective clothing and overshoes, eyewash facility, emergency shower.

STORAGE AND LABELING

STORAGE TEMPERATURE	INDOOR	HEATED	REFRIGERATED	OUTDOOR
below 90°F	YES	NO	NO	YES, if shaded

COMMENTS
Store only in original containers away from heat or heat sources. Limit storage of flammable liquids to approved areas equipped with overhead sprinklers. Store at ambient temperatures out of direct sunlight. Allow blanket of air over liquid in storage containers. Ground all containers when pouring or transferring, and keep closed when not in use. It is advisable to use the material within 6 months (check expiration dates on containers).

TOXICITY INFORMATION

Acute oral LD50 (rats) 7900 mg/kg.
Acute inhalation LC50 (rats) 12,500 to 16,500 ppm for 0.5 hours.
Acute dermal LD50 (rabbits) greater than 35,500 mg/kg.
Human Patch Test: About 1/3 of 50 subjects developed a mild erythema at the site of application. 20% of subjects showed evidence of sensitivity when tested 10 days later. (This toxicity information is based on Methyl Methacrylate.)

SHIPPING DATA

FREIGHT CLASSIFICATION	D.O.T. SHIPPING NAME
Flammable Liquid	Methyl Methacrylate Monomer Inhibited
TECHNICAL SHIPPING NAME	**D.O.T. HAZARD CLASSIFICATION**
Acrylic Resin	Flammable Liquid NOS UN1247

MISCELLANEOUS INFORMATION

KEEP OUT OF REACH OF CHILDREN!
Use SILIKAL products only for their intended purposes and only with other SILIKAL products as directed by the supplier.
DRUM DISPOSAL: THIS CONTAINER STILL HAZARDOUS WHEN EMPTY DO NOT CUT WITH TORCH! Product residue is flammable and hazardous. Do not reuse this container. Fill empty container with water, close, and dispose of in accordance with local, state and federal regulations.

DATE OF ISSUE
REVISED 10/87

NA - NOT APPLICABLE
NE - NOT ESTABLISHED
C - CEILING VALUE

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Stratford, Connecticut 06497 USA
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HAZARD RATING
4 = EXTREME
3 = HIGH
2 = MODERATE
1 = SLIGHT
0 = INSIGNIFICANT
* = CHRONIC HEALTH HAZARD – SEE SECTION IV

Fire: 0
Health: 1
Reactivity: 0
Special:

MATERIAL SAFETY DATA SHEET

PRODUCT NAME	CHEMICAL FAMILY
SILIKAL R7/17 Powder Component	Polymer Concrete Filler
CHEMICAL NAME & SYNONYMS	**FORMULA**

INGREDIENTS

*CAS #	COMPONENTS	WEIGHT %	TWA/TLV
7631-86-9	Quartz Sands	70-80	0.3 mg/m³ total dust
	Inert ingredients	less than 20	" "
	Acrylic Polymer	" " 3	NE
	Wetting Agent	" " 2	3 mg/M³
	Benzoyl Peroxide (phlegmatized)	" " 1	5 mg/M³

PHYSICAL DATA

APPEARANCE — ODOR			VISCOSITY
Grey powder; no odor			NA
MELTING OR FREEZING POINT	**BOILING POINT**	**VAPOR PRESSURE (mm Hg)**	**VAPOR DENSITY (AIR-1)**
NA	NA	NA	NA
SOLUBILITY IN WATER	**PERCENT VOLATILE (BY WEIGHT)**	**SPECIFIC GRAVITY (WATER = 1)**	**EVAPORATION RATE (BUTYL ACETATE = 1)**
Negligible	0	10.5 lbs/gal	NA

FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	AUTO IGNITION TEMPERATURE	LOWER EXPLOSION LIMIT (%)	UPPER EXPLOSION LIMIT (%)
Non-combustible	NA	NA	NA

EXTINGUISHING MEDIA
☐ FOAM ☐ "ALCOHOL" FOAM ☐ CO_2 ☐ DRY CHEMICAL ☐ WATER FOG ☐ OTHER

SPECIAL FIRE FIGHTING PROCEDURES

NA

UNUSUAL FIRE AND EXPLOSION HAZARDS

NA

HEALTH HAZARD DATA

RECOMMENDED TWA (MAXIMUM TIME - WEIGHTED - AVERAGE CONCENTRATION FOR AN 8-HOUR WORK PERIOD)

EFFECTS OF OVEREXPOSURE

Dust will cause imtation of the eyes, nose, throat. Repeated and prolonged contact with dust particles may cause lung congestion.

EMERGENCY AND FIRST AID PROCEDURES

Move subject to fresh air.
Flush eyes with large amount of water for at least 15 minutes. Consult a physician if irritation persists. Wash affected skin areas with soap and water.
Call a physician. Never give anything by mouth to an unconscious person.

*NOTE: CAS No. where not listed is proprietary. However, all materials are TSCA listed.

REACTIVITY DATA

STABILITY	CONDITIONS TO AVOID
Stable	

POLYMERIZATION	CONDITIONS TO AVOID
Will not occur	This material can initiate polymerization reactions with other organic materials (vinyl monomers).

INCOMPATABILITY (MATERIALS TO AVOID)
Other Use only as directed by supplier.

HAZARDOUS DECOMPOSITION PRODUCTS
Oxides of carbon

SPILL OR LEAK PROCEDURE

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
Sweep up spill and transfer to container for recovery. Keep dusting to a minimum.

WASTE DISPOSAL METHOD
Landfill according to local, state and federal regulations.

SPECIAL PROTECTION INFORMATION

VENTILATION TYPE	PROTECTIVE GLOVES
Normal room ventilation	Cotton or canvas
RESPIRATORY PROTECTION	**EYE PROTECTION**
Wear suitable MESA/NIOSH approved respirator where exposure limits are exceeded	Safety glasses (ANSI Z87.1, 1968)

OTHER PROTECTIVE EQUIPMENT

STORAGE AND LABELING

STORAGE TEMPERATURE	INDOOR	HEATED	REFRIGERATED	OUTDOOR

COMMENTS
CAUTION! Keep away from children. Silikal R7/17 powder should only be used for its intended purpose and only with other Silikal R7 or R17 liquid.

TOXICITY INFORMATION

SHIPPING DATA

FREIGHT CLASSIFICATION	D.O.T. SHIPPING NAME
Sand, NO	
TECHNICAL SHIPPING NAME	**D.O.T. HAZARD CLASSIFICATION**

MISCELLANEOUS INFORMATION

DATE OF ISSUE
Revised 12/87

NA = NOT APPLICABLE
NE = NOT ESTABLISHED
C = CEILING VALUE

This information contained herein is based on data considered accurate. However, no warranty is expressed or implied regarding the accuracy of these data or the results to be obtained from the use thereof. Vendor assumes no responsibility for injury to vendee or third person proximately caused by the material if reasonable safety procedures are not adhered to as stipulated in the data sheet. Additionally, vendor assumes no responsibility for injury to vendee or third persons proximately caused by abnormal use of the material even if reasonable safety procedures are followed. Furthermore, vendee assumes the risk in his use of the material.

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HAZARD RATING
4 - EXTREME
3 - HIGH
2 - MODERATE
1 - SLIGHT
0 - INSIGNIFICANT
* = CHRONIC HEALTH HAZARD – SEE SECTION IV

Fire 3, Health 3, Reactivity 2, Special

MATERIAL SAFETY DATA SHEET

PRODUCT NAME	CHEMICAL FAMILY
Silikal R41 Low Viscosity Primer Sealer	Polymer monomer blend of acrylic and methacrylic esters
CHEMICAL NAME & SYNONYMS	**FORMULA**
Acrylic Resin	$C_5H_8O_2$

INGREDIENTS

CAS #	COMPONENTS	WEIGHT %	TWA/TLV
80-62-6	Methyl Methacrylate	·77.0	100 ppm
	Polyfunctional Acrylic Ester	·5.0	400 ppm
N/A	Acrylic Polymers	·18.0	N.A.
	Tert. Amine based on P-Toluidine	·1.5	N.E.
N/A	Paraffin Wax	T	N.E.
	Alkylated Cresol	T	10 mg M^3

PHYSICAL DATA

APPEARANCE – ODOR			VISCOSITY
Water-like, slightly hazy liquid, acrid fruity odor			12 sec No. 4 Ford Cup
MELTING OR FREEZING POINT	**BOILING POINT**	**VAPOR PRESSURE (mm Hg)**	**VAPOR DENSITY (AIR=1)**
About -50°F	214°F (101°C)	40mm Hg	3.5 (Heavier than air)
SOLUBILITY IN WATER	**PERCENT VOLATILE (BY WEIGHT)**	**SPECIFIC GRAVITY (WATER = 1)**	**EVAPORATION RATE (BUTYL ACETATE = 1)**
Moderate	About 80	0.0973	About equal to BA

FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	AUTO IGNITION TEMPERATURE	LOWER EXPLOSION LIMIT (%)	UPPER EXPLOSION LIMIT (%)
42.8 F (6 C) Setaflash CC	815 F (435 C)	2.12	12.5

EXTINGUISHING MEDIA

☒ FOAM ☐ "ALCOHOL" FOAM ☒ CO_2 ☒ DRY CHEMICAL ☒ WATER FOG ☐ OTHER

SPECIAL FIRE FIGHTING PROCEDURES

Wear MESA/NIOSH approved self-contained breathing apparatus. Fight fires from safe distance or protected area. Use cold water spray to cool fire-exposed containers of Methyl Methacrylate.

UNUSUAL FIRE AND EXPLOSION HAZARDS

Vapors may travel to source of ignition and flash back. Heat, aging, or contamination may lead to polymerization and/or violent rupture of sealed containers. Cool warm or bulging containers to ambient temperature with water stream from safe distance. Then wear eye and face protection and protective clothing to carefully remove bung to vent pressure build-up. Reclose and dispose of container.

HEALTH HAZARD DATA

RECOMMENDED TWA (MAXIMUM TIME - WEIGHTED - AVERAGE CONCENTRATION FOR AN 8-HOUR WORK PERIOD)

TWA = 100 PPM THRESHOLD LIMIT VALUE (TLV) = 300 PPM (Based on Methyl methacrylate)

EFFECTS OF OVEREXPOSURE

High vapor concentration can cause irritation to eyes, skin, and respiratory system. Extended exposure can lead to headache, nausea, drowsiness, and unconsciousness. Direct liquid contact with eyes can cause severe irritation and possible corneal damage. Prolonged skin contact with liquid can cause irritation and skin rash.

DO NOT WEAR CONTACT LENSES WHEN USING THIS PRODUCT

EMERGENCY AND FIRST AID PROCEDURES

INHALATION: Move subject to fresh air. Give oxygen if breathing is difficult; artificial respiration if breathing has stopped.

CONTACT: Flush eyes with plenty of water for at least 15 minutes and get prompt medical attention. wash skin thoroughly with soap and water; remove and wash clothing before reuse.

INGESTION: If swallowed and victim is conscious, induce vomiting by giving two glasses of water for drink and sticking finger in throat. Immediately call a physician. Never induce vomiting or give anything by mouth to an unconscious person.

*NOTE: CAS No. where not listed is proprietary. However, all materials are TSCA listed.

REACTIVITY DATA

STABILITY	CONDITIONS TO AVOID
Stable	Heat and ignition sources. aging
POLYMERIZATION	**CONDITIONS TO AVOID**
May occur	Elevate temperatures. oxygen-free atmosphere. contamination

INCOMPATABILITY (MATERIALS TO AVOID)
Reducing agents. oxidizing agents (e g., rust). solid polymeric particles (e g . cured materials)

HAZARDOUS DECOMPOSITION PRODUCTS
Thermal decomposition may yield water. oxides of carbon. or acid fumes

SPILL OR LEAK PROCEDURE

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
Evacuate area. Eliminate ignition sources. Wear protective clothing and overshoes and MESA NIOSH approved respirator for vapor concentrations encountered. Dike spill with inert material (sand. earth. Fuller's earth. etc.) Transfer liquid and solid diking materials with non-sparking shovels to separate containers for disposal. KEEP SPILL OUT OF ALL SEWERS AND OPEN BODIES OF WATER. Follow emergency and first aid procedure.

WASTE DISPOSAL METHOD
Incinerate liquid in approved equipment. Landfill contaminated diking material. after allowing liquid to evaporate to reduce flash point to a safe level, according to current local. state. and federal regulations.

SPECIAL PROTECTION INFORMATION

VENTILATION TYPE	PROTECTIVE GLOVES
For indoor operations — explosion-proof mechanical ventilation to keep vapors below TWA and LEL	Impervious (e g . neoprene)
RESPIRATORY PROTECTION Wear MESA NIOSH approved chemical cartridge respirator for organic vapors where exposure limits are exceeded	**EYE PROTECTION** splashproof glasses (ANSI Z87.1. 1979)

OTHER PROTECTIVE EQUIPMENT
Protective clothing and overshoes. eyewash facility. emergency shower.

STORAGE AND LABELING

STORAGE TEMPERATURE	INDOOR	HEATED	REFRIGERATED	OUTDOOR
below 90 F	YES	NO	NO	YES. if shaded

COMMENTS
Store only in original containers away from heat or heat sources. Limit storage of flammable liquids to approved areas equipped with overhead sprinklers. Store at ambient temperatures out of direct sunlight. Allow blanket of air over liquid in storage containers. Ground all containers when pouring or transferring. and keep closed when not in use. It is advisable to use the material within 6 months (check expiration dates on containers).

TOXICITY INFORMATION

Acute oral LD50 (rats) 7900 mg kg
Acute inhalation LC50 (rats) 12.500 to 16.500 ppm for 0 5 hours
Acute dermal LD50 (rabbits) greater than 35.500 mg kg
Human Patch Test About 1 3 of 50 subjects developed a mild erythema at the site of application. 20% of subjects showed evidence of sensitivity when tested 10 days later. (This toxicity information is based on Methyl Methacrylate.)

SHIPPING DATA

FREIGHT CLASSIFICATION	D.O.T. SHIPPING NAME
Flammable Liquid	Methyl Methacrylate Monomer Inhibited
TECHNICAL SHIPPING NAME	**D.O.T. HAZARD CLASSIFICATION**
Acrylic Resin	Flammable Liquid NOS UN1247

MISCELLANEOUS INFORMATION

KEEP OUT OF REACH OF CHILDREN!
Use SILIKAL products only for their intended purposes and only with other SILIKAL products as directed by the supplier.
DRUM DISPOSAL: THIS CONTAINER STILL HAZARDOUS WHEN EMPTY DO NOT CUT WITH TORCH! Product residue is flammable and hazardous. Do not reuse this container. Fill empty container with water. close. and dispose of in accordance with local. state and federal regulations.

DATE OF ISSUE
REVISED 10/87

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C = CEILING VALUE

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2 = MODERATE
1 = SLIGHT
0 = INSIGNIFICANT
* = CHRONIC HEALTH HAZARD — SEE SECTION IV

Fire	Health	Reactivity	Special
2	2	4	OXY

MATERIAL SAFETY DATA SHEET

PRODUCT NAME	CHEMICAL FAMILY
SILIKAL Powder Hardner	Organic Peroxide
CHEMICAL NAME & SYNONYMS	**FORMULA**
Benzoyl Peroxide (BPO)	$(C_6H_5CO)_2O_2$

INGREDIENTS

☆CAS #	COMPONENTS	WEIGHT %	TWA/TLV
94-30-0	Benzoyl Peroxide (moderate health and extreme reactivity hazard)	50	5 mg/M³ (OSHA)
	Phthalate Plasticizer	50	

PHYSICAL DATA

APPEARANCE — ODOR			VISCOSITY
Fine white granules; slight odor.			NA
MELTING OR FREEZING POINT	**BOILING POINT**	**VAPOR PRESSURE (mm Hg)**	**VAPOR DENSITY (AIR-1)**
NA	NA	NE	NA
SOLUBILITY IN WATER	**PERCENT VOLATILE (BY WEIGHT)**	**SPECIFIC GRAVITY (WATER = 1)**	**EVAPORATION RATE (BUTYL ACETATE = 1)**
Negligible	0	36 lbs/cu. ft.	NA

FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	AUTO IGNITION TEMPERATURE	LOWER EXPLOSION LIMIT (%)	UPPER EXPLOSION LIMIT (%)
NA	NA	NA	NA

EXTINGUISHING MEDIA

☒ FOAM ☐ "ALCOHOL" FOAM ☒ CO_2 ☒ DRY CHEMICAL ☒ WATER FOG ☒ OTHER

SPECIAL FIRE FIGHTING PROCEDURES

Wear MESA/NIOSH approved self-contained breathing apparatus. Fight fires with water from an explosion resistant location. In the dry state benzoyl peroxide is highly flammable and at elevated temperatures becomes unstable and spontaneously explosive.

UNUSUAL FIRE AND EXPLOSION HAZARDS

EXTREMELY REACTIVE MATERIAL. Explosion sensitive to heat, shock, friction. Prevent contamination with other chemicals or transfer equipment contaminated with other chemicals. CONTAMINATION CAN LEAD TO FIRE OR EXPLOSIVE DECOMPOSITION. Do not add materials to containers, including previously removed SILIKAL material.

HEALTH HAZARD DATA

RECOMMENDED TWA (MAXIMUM TIME - WEIGHTED - AVERAGE CONCENTRATION FOR AN 8-HOUR WORK PERIOD)

5 mg M³ (OSHA)

EFFECTS OF OVEREXPOSURE

Contact will cause eye inflammation and may cause skin irritation.

EMERGENCY AND FIRST AID PROCEDURES

In case of contact, flush eyes thoroughly with large amount of water for at least 15 minutes. Consult a physician if irritation persists. Wash affected skin areas thoroughly with soap and water.

If swallowed and victim is conscious, immediately give two glasses of water to drink and induce vomiting. Call a physician.

☆NOTE: CAS No. where not listed is proprietary. However, all materials are TSCA listed.

REACTIVITY DATA

STABILITY	CONDITIONS TO AVOID
Unstable	Heat, sparks, shock (impact, blows), and friction; contamination.
POLYMERIZATION	CONDITIONS TO AVOID
Will not occur	

INCOMPATABILITY (MATERIALS TO AVOID)
Strong oxidizers, reducing agents, mineral acids, azines, accelerators.

HAZARDOUS DECOMPOSITION PRODUCTS
Thermal decomposition may yield biphenyl (TLV 0.2 ppm)

SPILL OR LEAK PROCEDURE

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
Any spilled powder hardener should be swept up and burned immediately. Using a non-sparkin shovel, deposit the solid in small shallow piles on several sheets of newspaper (outside in a safe place) and ignite with a torch having a six foot handle and back away. No more than one (1) lb. of powder hardener should be burned at one time.

WASTE DISPOSAL METHOD
Use same method as for spill or leak. Do not reuse empty container.

SPECIAL PROTECTION INFORMATION

VENTILATION TYPE	PROTECTIVE GLOVES
Normal room ventilation.	Impervious (e g . neoprene)
RESPIRATORY PROTECTION	EYE PROTECTION
None required for normal operation.	(ANSI Z87.1, 1968)

OTHER PROTECTIVE EQUIPMENT
Eyewash facility

STORAGE AND LABELING

STORAGE TEMPERATURE	INDOOR	HEATED	REFRIGERATED	OUTDOOR
Maximum 80°F	YES	NO	PREFERRED	NO

COMMENTS
Store in original containers. Do not store near sources of heat or ignition such as radiators, steampipes, or open flames. Protect from direct sunlight. Special care must be taken to avoid contamination with combustible materials which could induce decomposition. Keep container closed when not in use. Do not add to hot water.

TOXICITY INFORMATION

SHIPPING DATA

FREIGHT CLASSIFICATION	D.O.T. SHIPPING NAME
Benzoyl Peroxide, Organic Peroxide	
TECHNICAL SHIPPING NAME	D.O.T. HAZARD CLASSIFICATION
	ORGANIC PEROXIDE SOLID NOS CHEMICAL NOIBN 2089

MISCELLANEOUS INFORMATION

KEEP OUT OF REACH OF CHILDREN!
Use Silikal Powder Hardener only with Silikal resins and only for its intended purpose as directed by the supplier
For more information consult Chemical Safety Data Sheet SD-81, Manufacturing Chemists Association, Publications Department, 1825 Connecticut Avenue, Washington D C 20009

DATE OF ISSUE
REVISED 10/87

NA = NOT APPLICABLE
NE = NOT ESTABLISHED
C = CEILING VALUE

MATERIAL SAFETY DATA SHEET

Master Builders, Inc., 23700 Chagrin Blvd., Cleveland, Ohio 44122
Emergency Phone: 216-831-5500

SET 45

Revision Date: 8-23-89

1. PRODUCT NAME: SET 45

   CHEMICAL FAMILY: Inorganic Salts

2. HAZARDOUS INGREDIENTS:

HAZARDOUS INGREDIENTS	LD50/LC50	TLV	STEL	PEL	CONTENT
Silica, quartz CAS No. 14808-60-7		0.1 mg/m3 (Respirable Dust)			>60%

3. PHYSICAL DATA:

Boiling Point:	Not Applicable	Water/Oil Distribution Coefficient:	Not Applicable
Percent Volatile:	Not Applicable	Solubility in Water:	Slight
Freezing Point:	Not Applicable	Specific Gravity:	Not Applicable
Vapor Density:	Not Applicable	pH:	Not Applicable
Evaporation Rate:	Not Applicable		
Odor Threshold:	Not Applicable		
Appearance and Odor:	Dark Gray Odorless Powder		

4. FIRE AND EXPLOSION HAZARD DATA:

   Flash Point: Not Applicable   Method Used: Not Applicable

   Auto-Ignition Temperature: Not Applicable
   LEL: Not Applicable   UEL: Not Applicable

   Extinguishing Media: This material does not give a flash point by conventional test methods. Use extinguishing agent suitable for type of surrounding fire.

   Special Fire & Unusual Hazards: Not Applicable

5. REACTIVITY DATA:

   Stability: Stable

   Incompatibility: Strong Mineral Acids, Oxidizing Agents

   Hazardous Decomposition Products: Not Applicable

   Hazardous Polymerization: None will occur.

6. ENVIRONMENTAL & DISPOSAL INFORMATION:

Action to Take for Spills/Leaks:	No special procedures are required for clean-up of spills or leaks of this material. Sweep up and return for reuse or discard.
Waste Disposal Method:	This product, when discarded or disposed of, is not listed as a hazardous waste in Federal regulations. Dispose in a landfill in accordance with local, state, and federal regulations.

7. HEALTH HAZARD DATA: HAZARD RATING NO. 2 (Moderate Hazard) - Temporary or minor injury may occur.
PRIMARY ROUTE(S) OF ENTRY: Inhalation
Effects of Overexposure

Inhalation:	Nuisance dust may cause temporary but reversible respiratory problems.
Eyes:	Abrasive action may cause damage to the outer surface of the eye.
Skin Contact:	In combination with water, dermal exposure may cause skin irritation.
Skin Absorption:	Not Applicable
Ingestion:	Not Applicable
Chronic:	Repeated inhalation of respiratory silica in excess of the TLV over extended periods can result in irreversible fibrosis of the lungs (silicosis). An IARC evaluation concluded that there is limited evidence that crystalline silica may be carcinogenic to humans.

8. FIRST AID:

Inhalation:	Remove individual to fresh air.
Eyes:	Flush with large quantities of water for at least 15 minutes; seek immediate medical attention.
Skin:	Wash with soap and water; get medical attention if exposure is extensive; remove clothing and wash before reuse.
Ingestion:	Not Applicable

9. SPECIAL PROTECTION INFORMATION:

Ventilation:	Ventilation may be used to control or reduce airborne concentrations.
Personal Protective Equipment:	Impervious gloves are recommended; goggles or glasses to prevent eye contact; where dust is excessive use a NIOSH approved dust mask.

10. ADDITIONAL INFORMATION:

Hazardous Materials Classification:	Not Applicable
WHMIS Classification:	Class D
Storage Conditions:	Store away from moist damp environment.
Special Instructions:	None

The information herein is given in good faith. No warranty, expressed or implied, is given regarding the accuracy of these data or the results obtained from the use thereof. Consult Master Builders, Inc., Environmental Affairs, for further information.

5302/1

PYRAMENT
A Division of Lone Star Industries, Inc.
P. O. Box 2148, 402 Concrete Avenue
Houston, Texas 77252
****

MATERIAL SAFETY DATA SHEET
(OSHA 29 CFR 1910.1200)
FOR PYRAMENT® 505 RAPID CONCRETE REPAIR MATERIAL

SECTION I - IDENTITY

Manufacturer's Name and Address
Pyrament
A Division of Lone Star Industries, Inc.
P. O. Box 2148
Houston, TX 77252

Emergency Telephone Number
(713) 921-4861
(713) 485-5381

Information Telephone Number
(713) 921-4861
(713) 921-5221

Date of Preparation
August 1, 1988

SECTION II - HAZARDOUS INGREDIENTS/IDENTITY INFORMATION

Common Name	Ingredients*
Blended Cement	Specific chemical identity is being withheld as a trade secret.

Registered Trademarks
Pyrament® 505

* Hazardous - Caustic

SECTION III - PHYSICAL/CHEMICAL CHARACTERISTICS

Solubility in Water - Slight (0.1 - 1.0%)
Specific Gravity - (bulk) 1.25.
Gray Colored Powder With No Odor.

The following properties are not applicable as Pyrament® 505 is a solid in powder form:

Boiling point, vapor pressure, vapor density, melting point, evaporation rate.

SECTION IV - FIRE AND EXPLOSION HAZARD DATA
Pyrament® 505 is noncombustible and not explosive.

SECTION V - REACTIVITY DATA

Pyrament• 505 is stable.

Pyrament• 505 is not incompatible with other materials, will not decompose into hazardous by-products and will not polymerize.

Keep Pyrament• 505 dry until used.

Pyrament• 505 is reactive with acid, aluminum, tin, and zinc.

SECTION VI - HEALTH HAZARD DATA

Pyrament• 505 can irritate or burn eyes, skin and tissue. do not ingest -- corrosive.

Pyrament• 505 may be classified as a nuisance dust by OSHA, MSHA and ACGIH. As such, the TLV is 5 mg/m^3 for respirable dust and 10 mg/m^3 for total dust. Pyrament• 505 is not know to cause cancer. Exposure to Pyrament• 505 can affect the skin, the eyes and mucous membranes. Acute Exposure: Pyrament• 505, especially as an ingredient in plastic (unhardened) concrete, mortar or slurries, can dry the skin and cause alkali burns. Pyrament• 505 dust can irritate the eyes and upper respiratory system.
Chronic Exposure: Pyrament• 505 dust can cause inflammation of the lining tissue of the interior of the nose and inflammation of the cornea. Individuals who are allergic to chromium may develop an allergic dermatitis. (Pyrament• 505 may contain traces of chromium).
Emergency First Aid Procedures: Irrigate (flood) eyes immediately and repeatedly with clean water. Wash exposed skin areas with soap and water. Apply sterile dressings. Get prompt medical attention.

SECTION VII - PRECAUTIONS FOR SAFE HANDLING AND USE

The use of barrier creams or impervious gloves, boots and clothing to protect the skin from contact with wet Pyrament• 505 is recommended.

Following work with Pyrament• 505, workers should wash exposed areas with soap and water.

Store away from acids in tightly sealed container.

If Pyrament• 505 is spilled, it can be cleaned up using dry methods that do not disperse dust into the air. Avoid breathing dust and provide eye protection.

Pyrament• 505 can be treated as a common waste for disposal or returned to the container for later use if it is not contaminated or wet.

SECTION VIII - CONTROL MEASURE

See Section VII.